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Test Problems for Reactive Flow HE Model in the ALE3D Code and Limited Sensitivity Study

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Test Problems for Reactive Flow HE Model in the ALE3D Code And Limited Sensitivity Study

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Abstract

We document quick running test problems for a reactive flow model of HE initiation incorporated into ALE3D. A quarter percent change in projectile velocity changes the outcome from detonation to HE burn that dies down. We study the sensitivity of calculated HE behavior to several parameters of practical interest where modeling HE initiation with ALE3D.

Introduction

ALE3D is a 3D Arbitrary Lagrange Eulerian (ALE) finite element code that treats fluid and elastic plastic response of materials on an unstructured grid. A phenomenological model of HE initiation called the Ignition and Growth Model (IGM) which uses reactive flow has been developed at LLNL [1,2] and is incorporated in the code [3]. In this report we document quick running test problems that use the IGM. Running these problems ensures that new releases of the code produce results consistent with past versions. We also examine the dependence of results of these test problems on several parameters of practical interest when modeling initiation of HE with the IGM.

Test Problem Model

The test problems model experiments which have been performed at the Naval Research Laboratory, to provide data on HE behavior near detonation threshold in axisymmetric geometry. The experiments were originally modeled with the CALE code, and experimental results have been used to refine the IGM model parameters for Comp-B which was used in the experiments. The test series consisted of balls of different materials shot at normal incidence onto round pills of Comp-B. The Comp-B is cased with tantalum in the direction facing the projectile, steel on the backside and aluminum on the outside. Projectiles are spheres of tungsten or Lexan. We choose to model experiments which produce the lowest pressure in the HE: impacts of 76 mm diameter Lexan spheres. An initial velocity of 1.38 km/sec produced a delayed explosion, one at 1.44 km/sec a detonation. Because of the symmetry of the problem, the model is set up as only one quarter of the test geometry. Reflecting boundaries are used in the two planes of symmetry, all other boundaries are open. In the original modeling of the experiments with the CALE code the initial problem setup was devoid of mixed zones, and the HE stayed that way through most of the calculation. We set up the mesh so that boundaries of the HE and surrounding materials are coincident with zonal boundaries. This allows the HE and surrounding materials to be initially made up of clean zones. Inhibition of advection in the HE during the run can keep it free of mixed zones as desired. Zoning is relatively coarse in the directions normal to the projectile velocity: ~8 mm on average, but this is reasonable in view of the large projectile dimension. In the direction of the projectile velocity, we start with 4 mm zoning in the projectile, 2 mm zoning in the HE and backplate and ~1.2 mm zoning in the thin tantalum front plate. Material weights keep zoning concentrated in the front plate and the HE as the mesh is relaxed during the run. We start out by relaxing the mesh for 100 iterations. A materials map with zoning indicated is shown at that point in Figure 1.

Test problem runs output

We started out with our standard test problems documented in the appendix with an initial projectile velocity of 1.38 km/s and 1.44 km/s run with version 2.9.0 of ALE3D. The evolution of the 1.38 km initial projectile velocity run is shown in Figures 2 through 12, which are quad views of the calculation with the two symmetry planes at the front and left. The right side of each figure shows the total zonal burned HE fraction (top, scale of 0: blue to 1: red) and zonal pressure (bottom, scale of 0: blue to 100 kbar: red) in the HE. Pressure within the HE peaks between 40 μs and 45 μs, and HE burn becomes negligible after 70 μs. The evolution of the 1.44 km/s initial projectile velocity run is shown in Figures 13 through 17. Pressure builds up in the middle of the HE pill by 35 μs and a detonation soon follows. We stopped the calculation at 45 μs since the outcome is clear, while the time step which is controlled by HE burn is very small.

We varied the projectile velocity by 0.005 km/s to establish the detonation threshold. The evolution of a 1.385 km/s initial projectile velocity run is shown in Figures 18 through 28. The HE behavior is very similar to that of the 1.38 km/s initial projectile velocity, although there is a bit more burned HE. The evolution of a 1.390 km/s initial velocity run is shown in Figures 29 through 37. The HE behavior is similar to that of the 1.385 km/s initial projectile velocity run up to 40 μs. At 45 μs pressure in the HE is higher and more HE has burned. HE pressure builds up until a detonation takes off at 60 μs at the rear of the HE pill. The initial projectile velocity differs by only 0.36 percent. The result is radically different HE behavior. These two runs are a sensitive test of the model performance in the code.

Limited sensitivity study

We are interested in the dependence of the HE response calculated with the IGM model to some parameters which are often altered in calculations, and initial setup conditions.

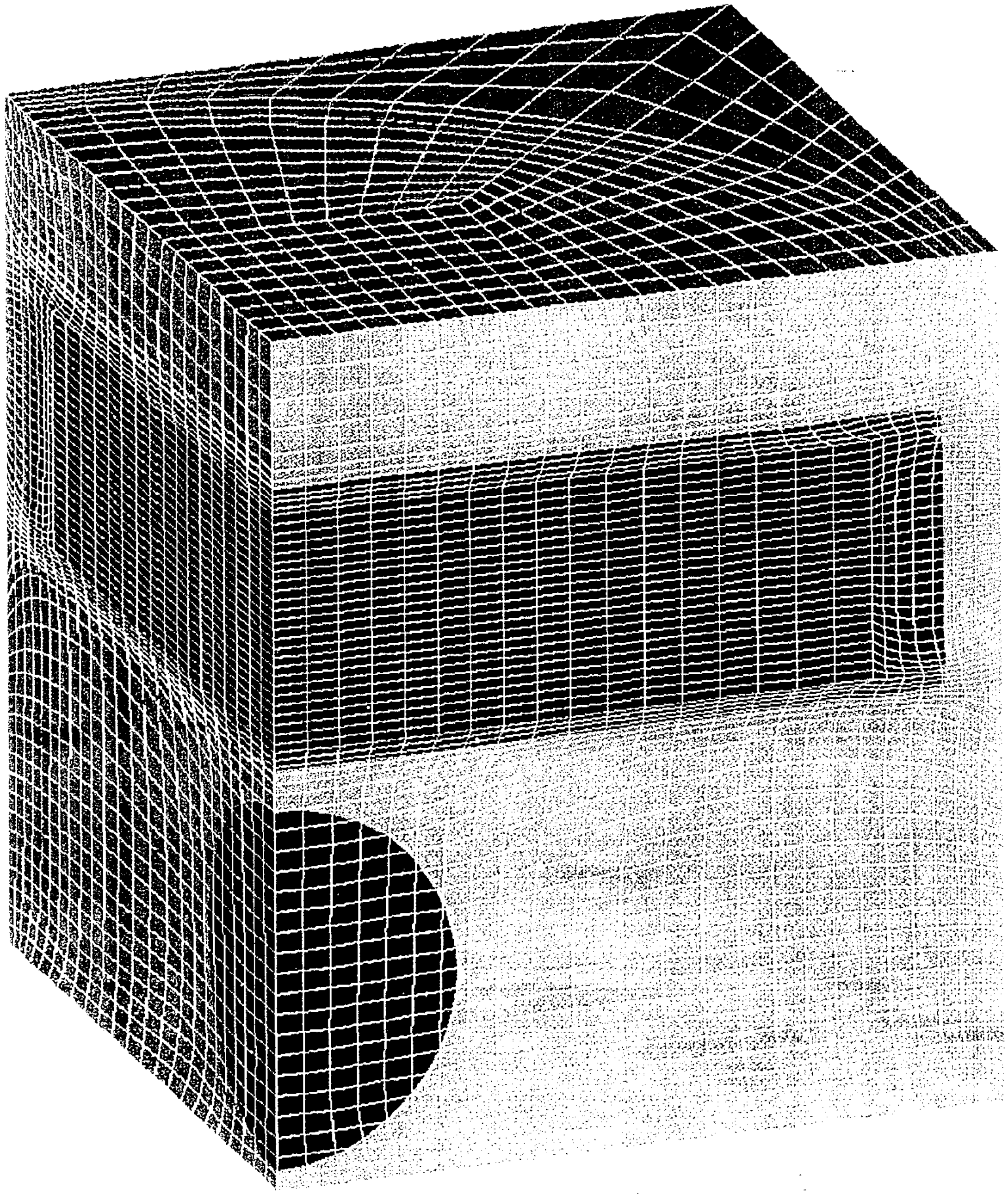

Figure 1: Materials map at start of problem with zoning indicated. The front and left faces are symmetry planes. Red = Lexan projectile, green = tantalum cover, dark blue = HE, purple = steel back plate, light blue = aluminum outer ring, yellow = air.

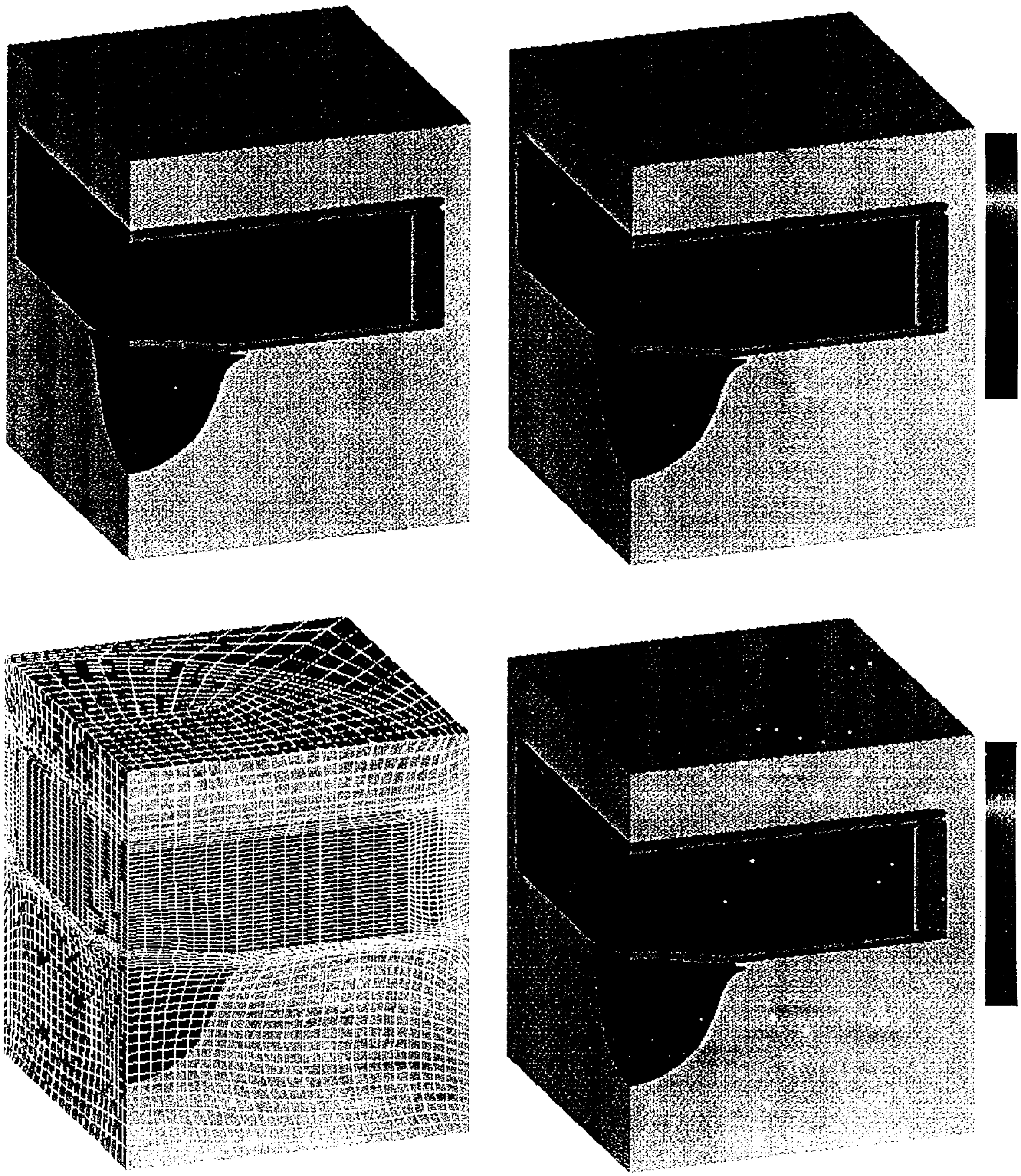

Figure 2: Initial projectile velocity 1.38 km/s at 25 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

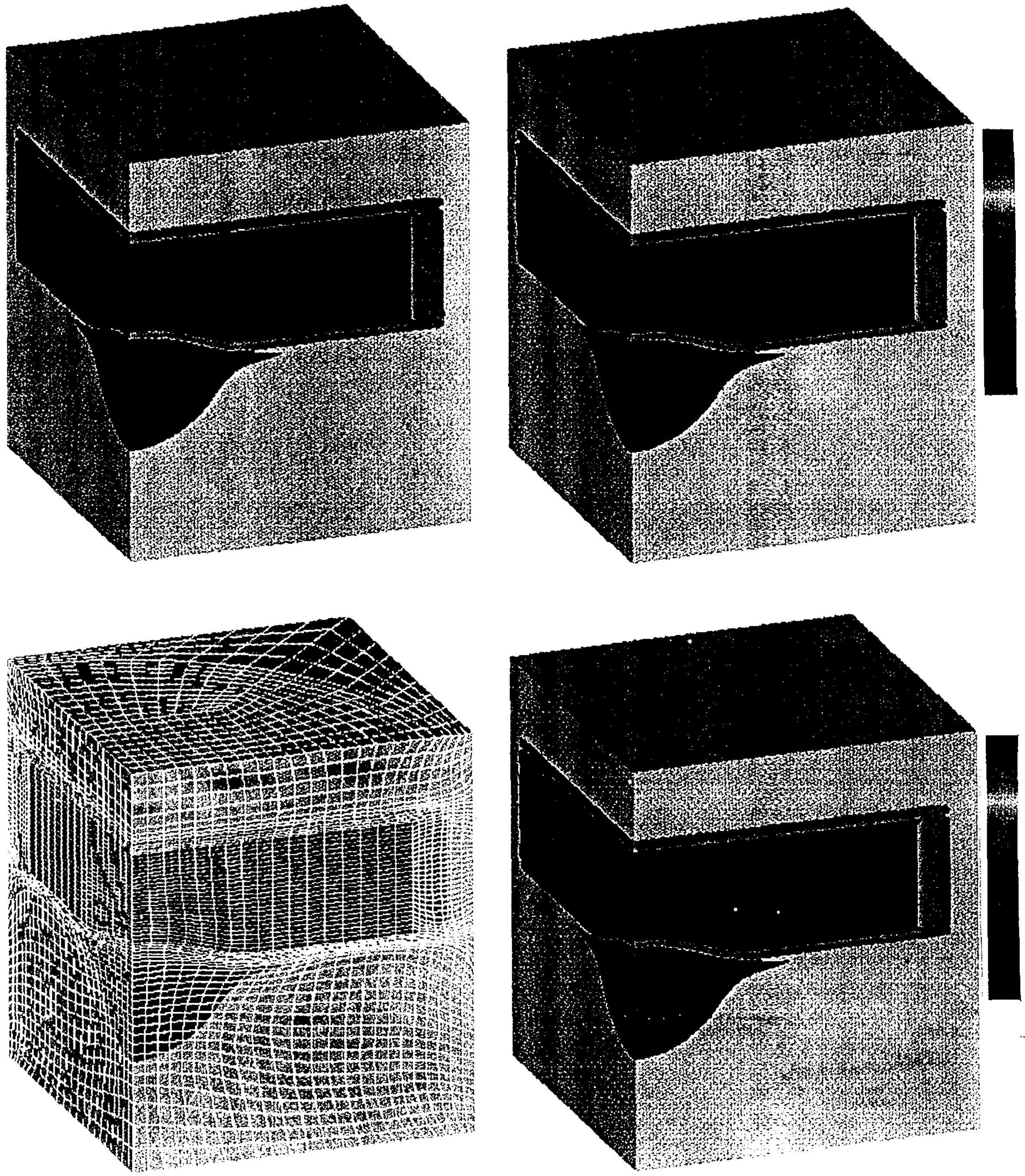

Figure 4: Initial projectile velocity 1.38 km/s at 35 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

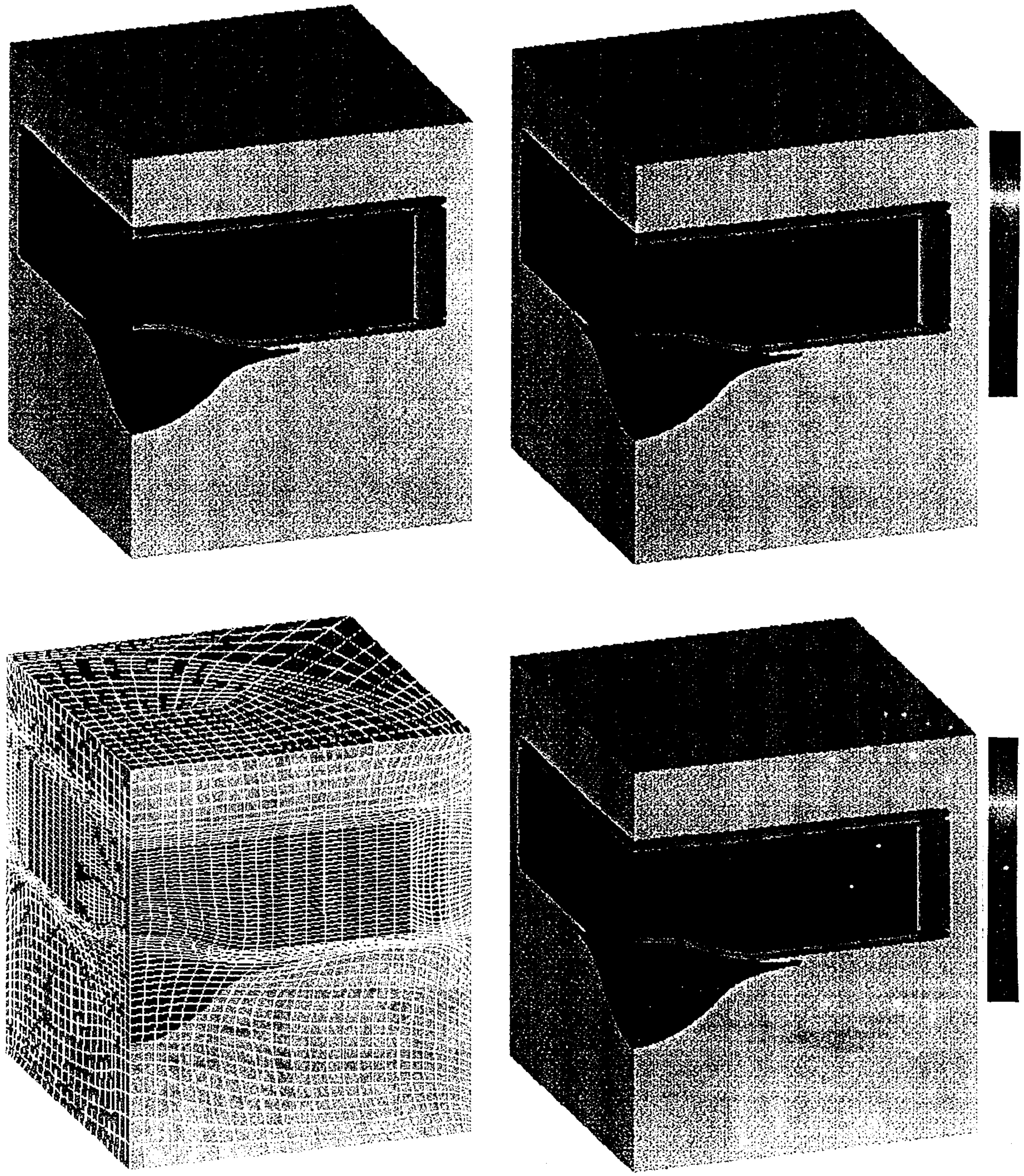

Figure 5: Initial projectile velocity 1.38 km/s at 40 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

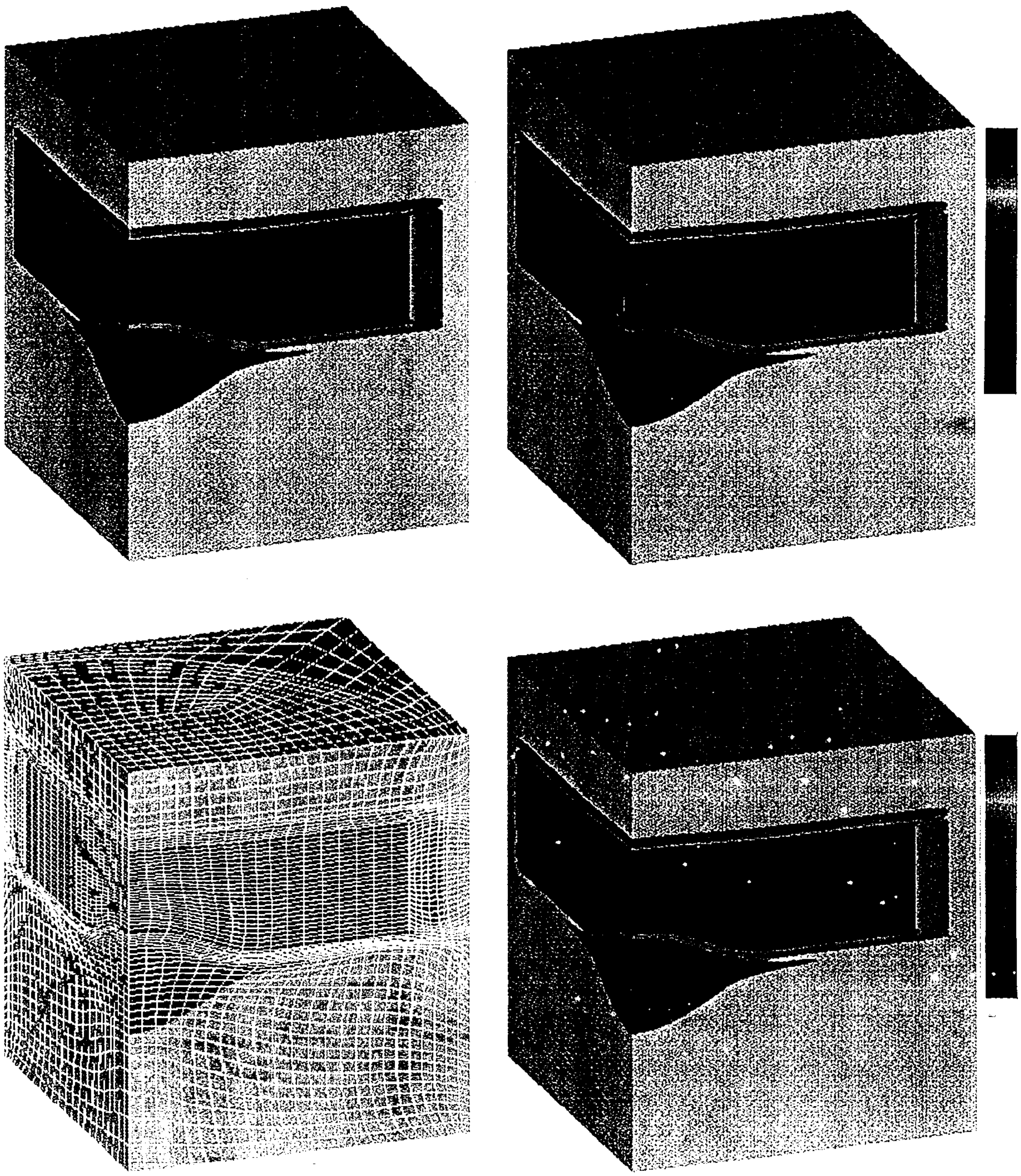

Figure 6: Initial projectile velocity 1.38 km/s at 45 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

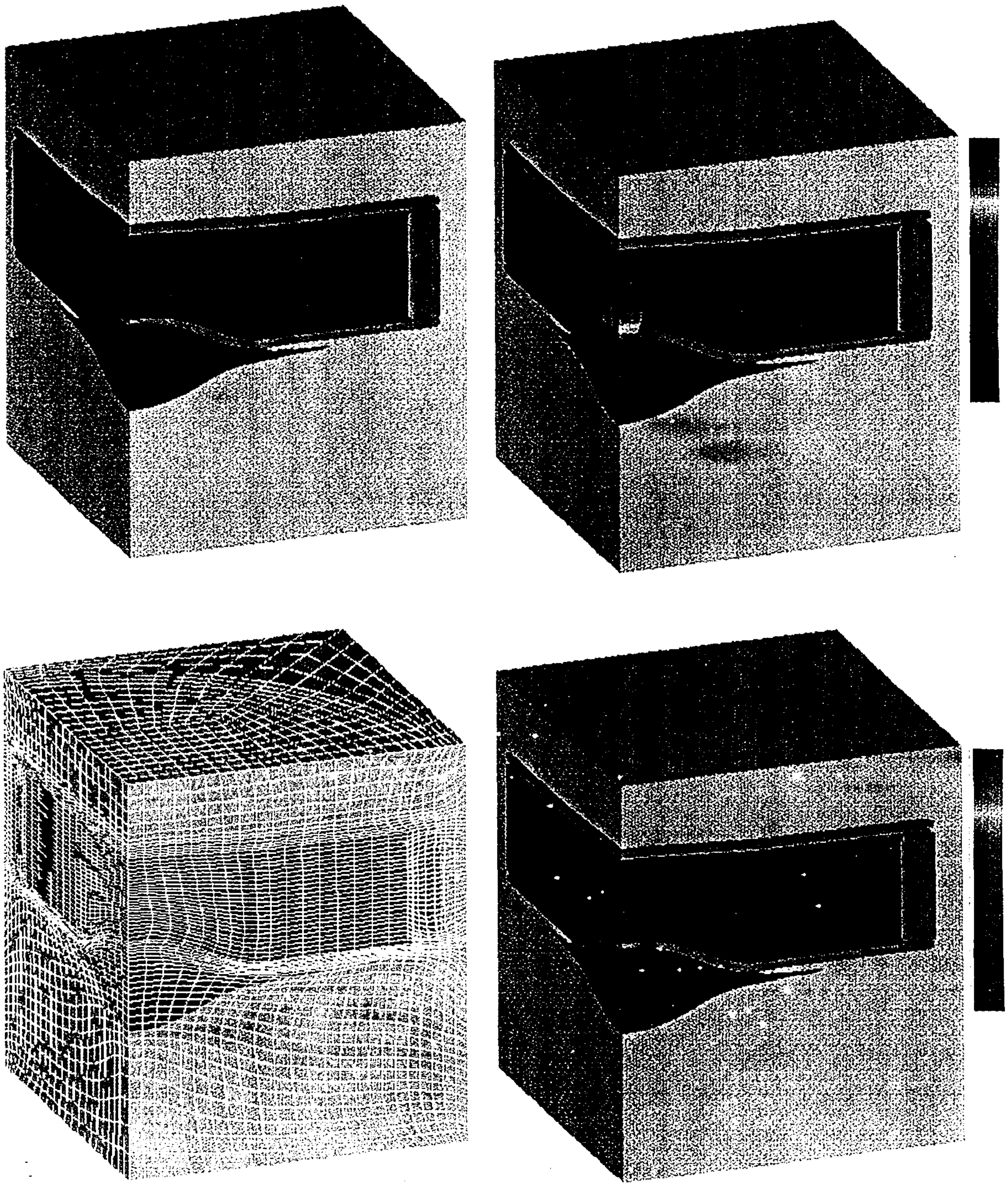

Figure 7: Initial projectile velocity 1.38 km/s at 50 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

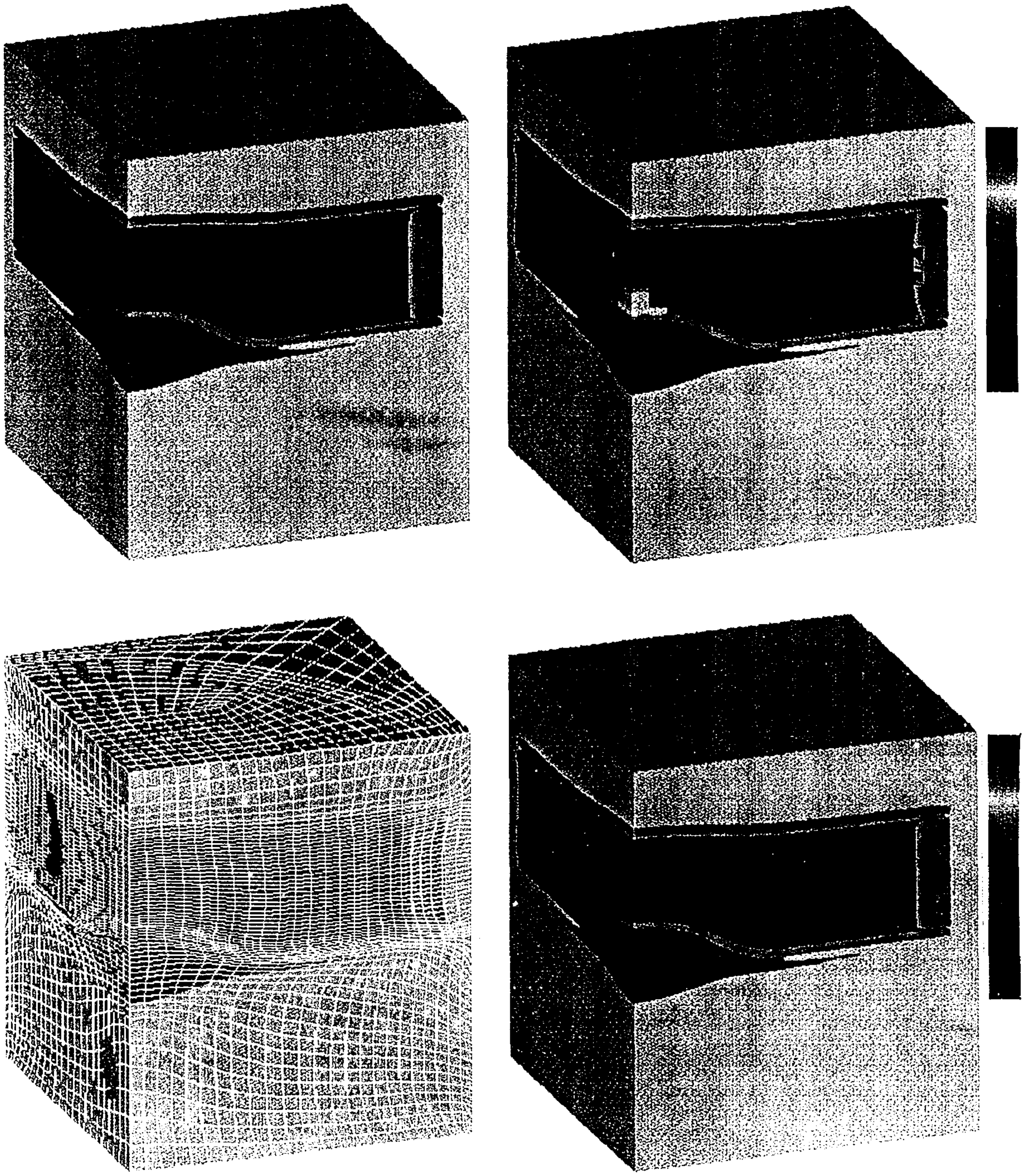

Figure 8: Initial projectile velocity 1.38 km/s at 60 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

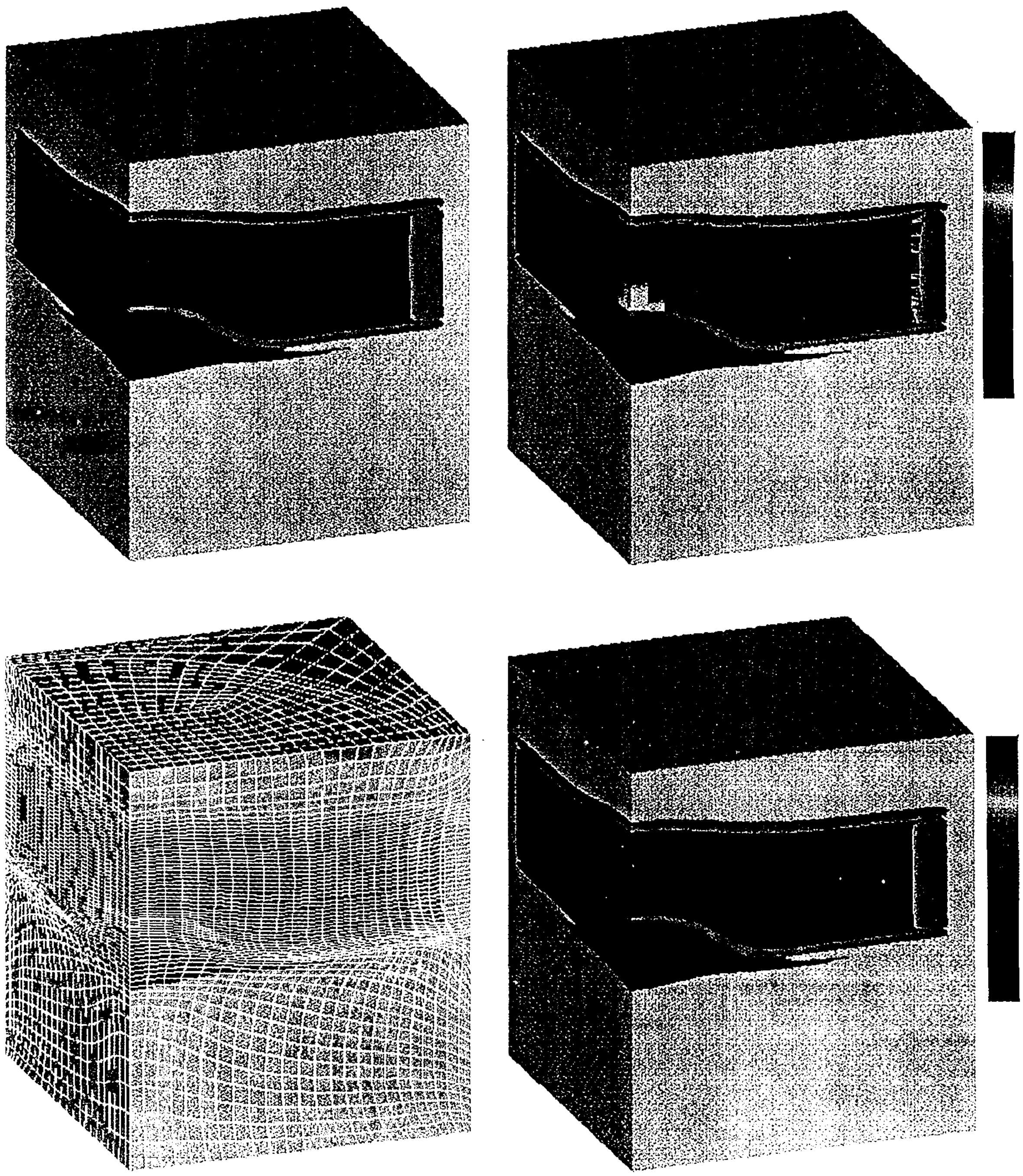

Figure 9: Initial projectile velocity 1.38 km/s at 70 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

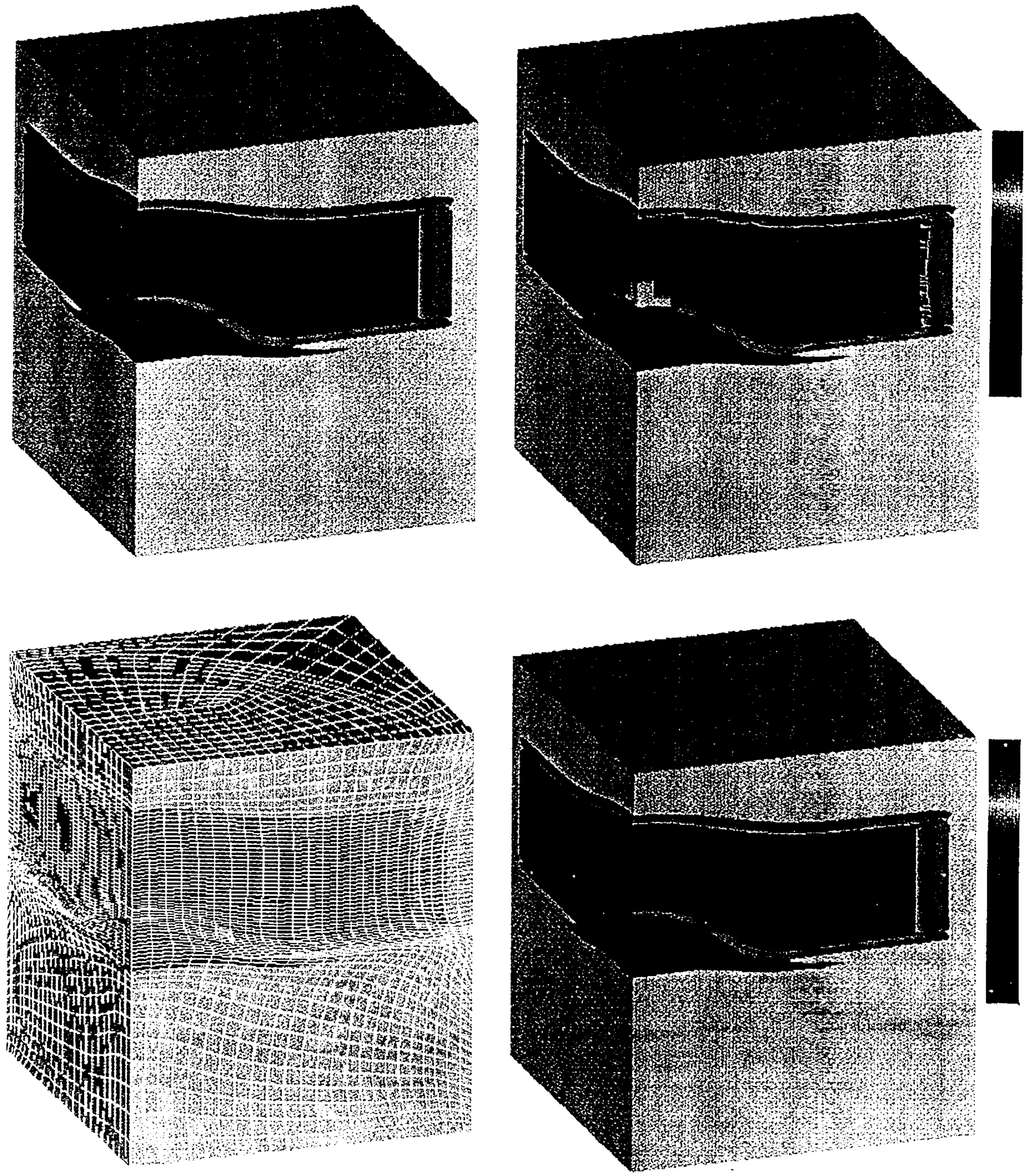

Figure 10: Initial projectile velocity 1.38 km/s at 80μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

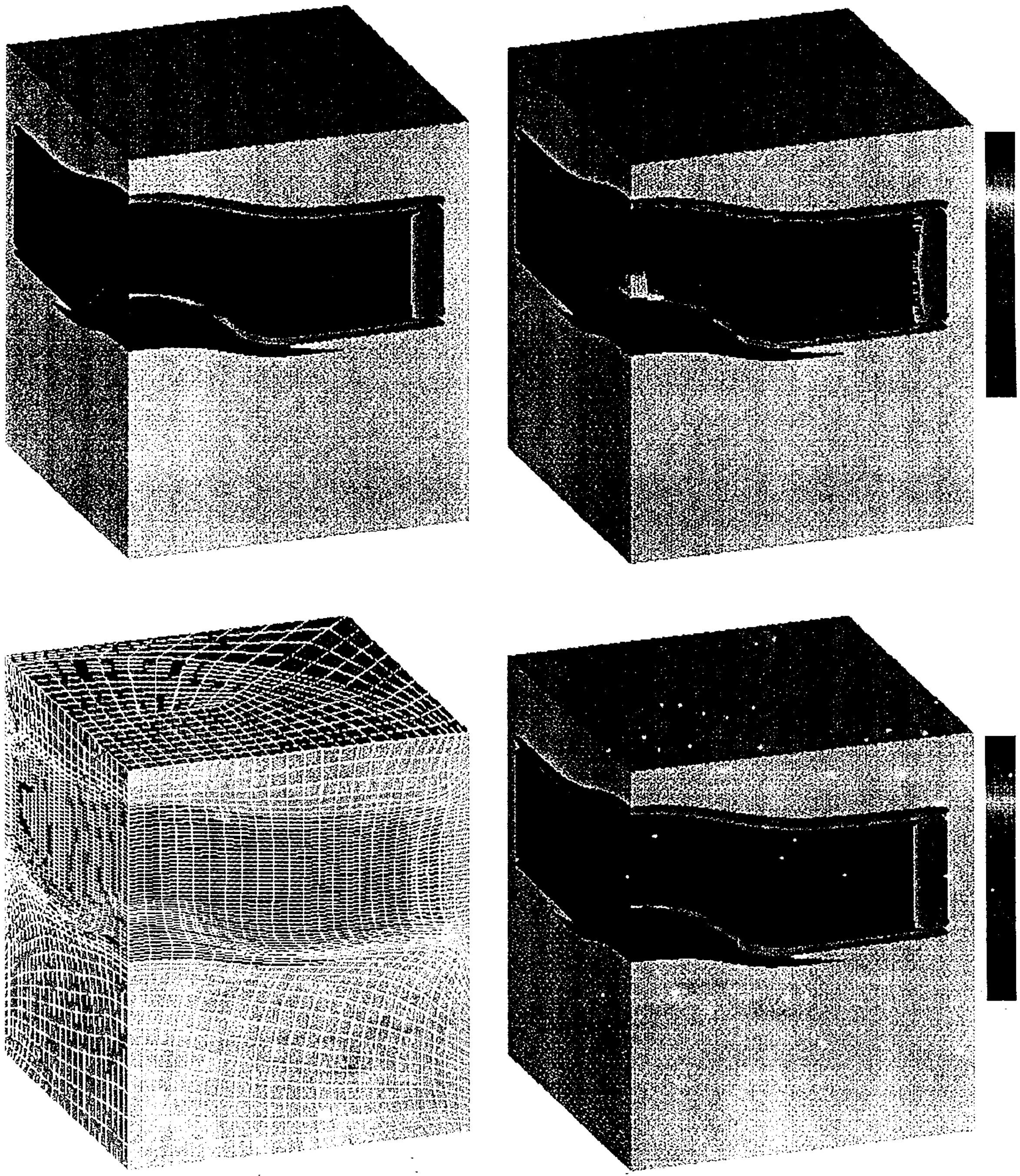

Figure 11: Initial projectile velocity 1.38 km/s at 90μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

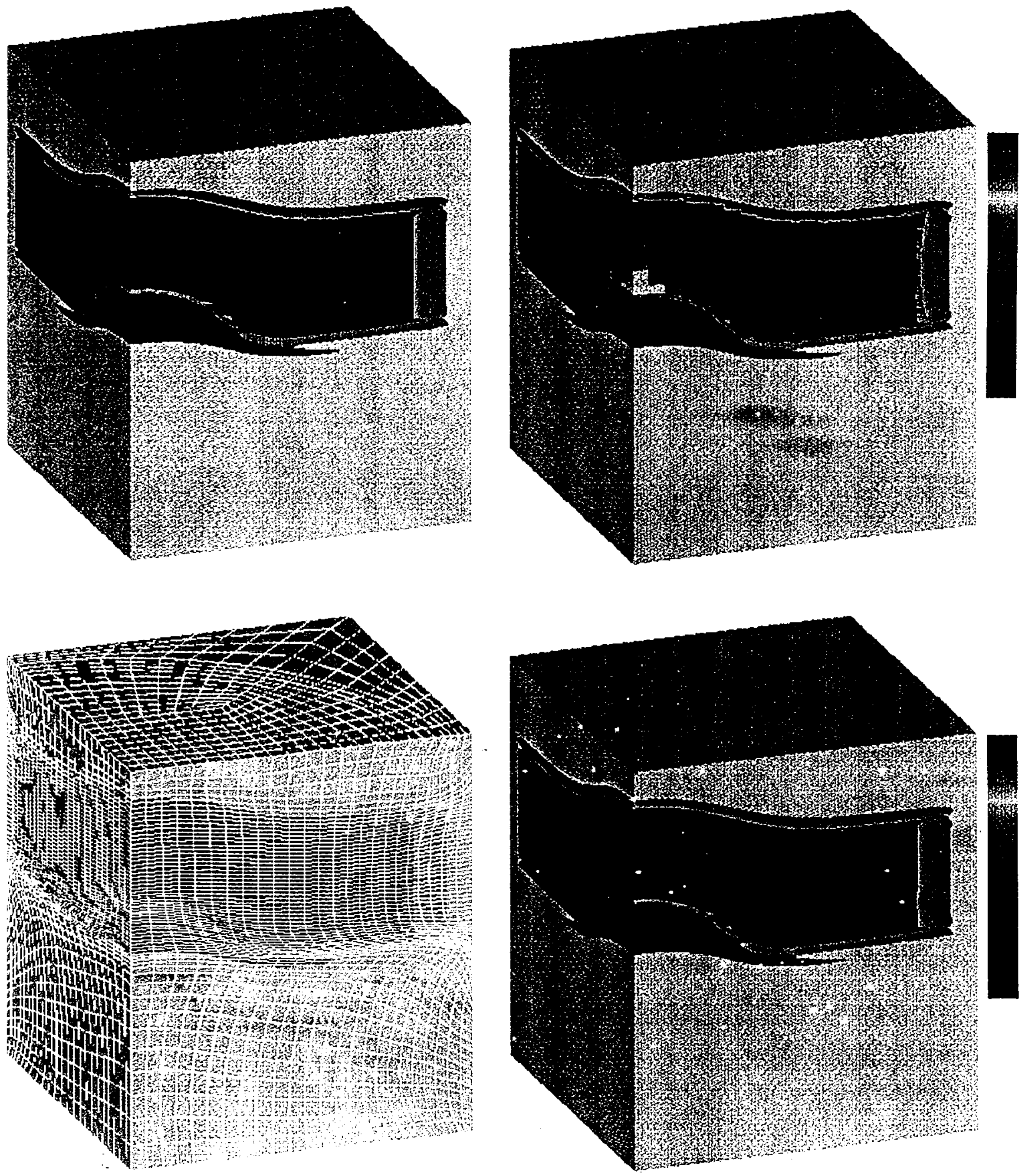

Figure 12: Initial projectile velocity 1.38 km/s at 100 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

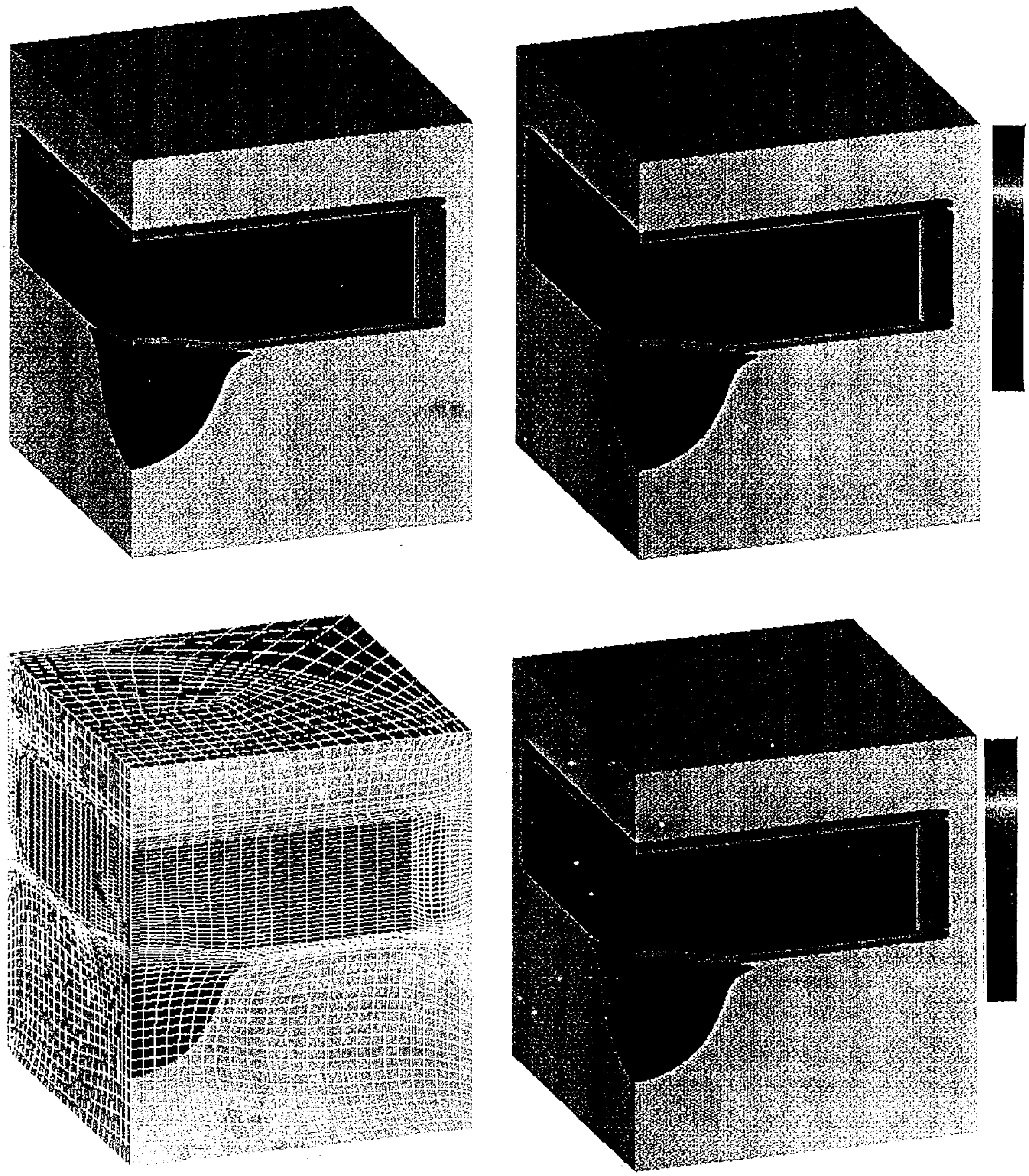

Figure 13: Initial projectile velocity 1.44 km/s at 25 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

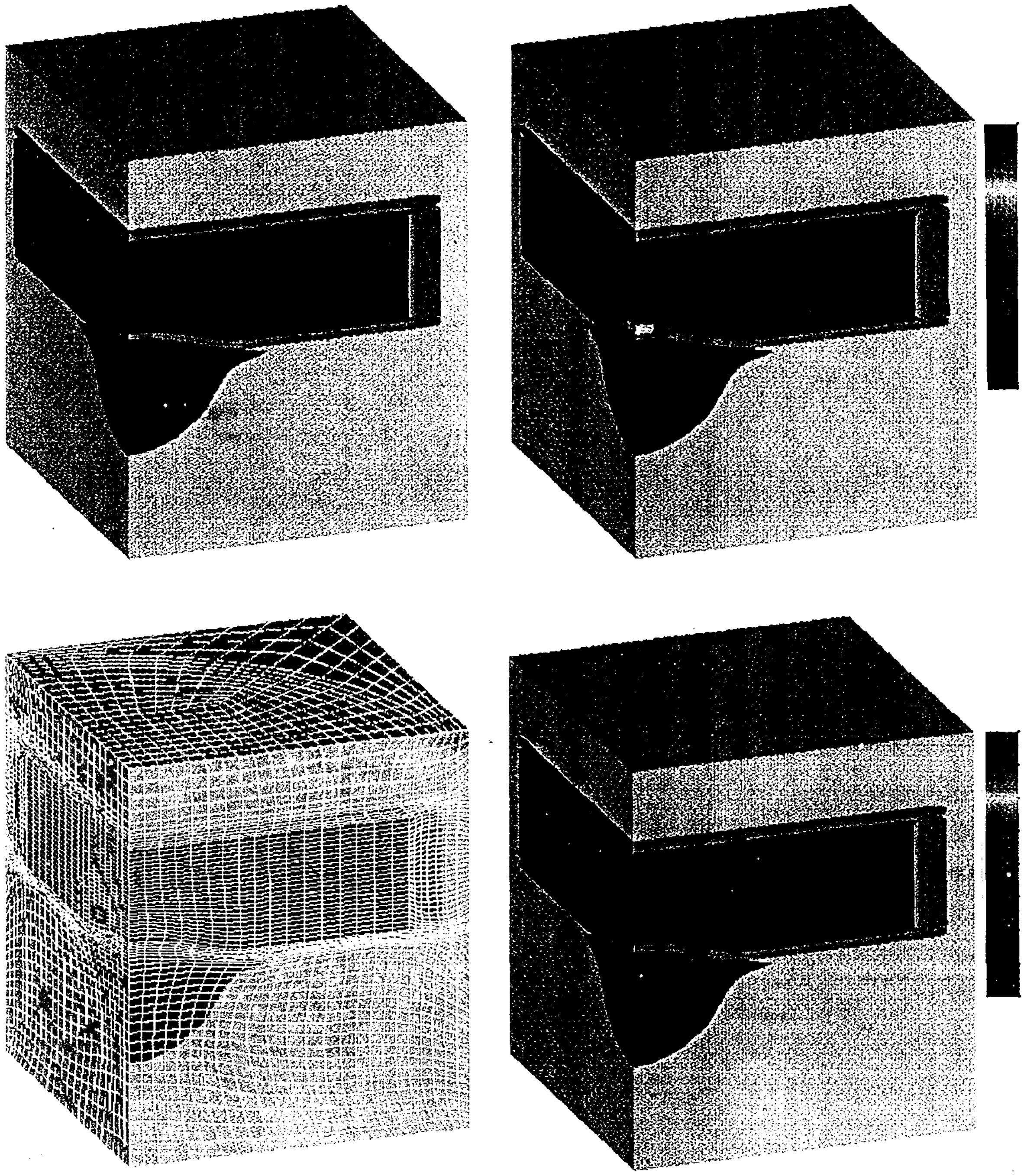

Figure 14: Initial projectile velocity 1.44 km/s at 30 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

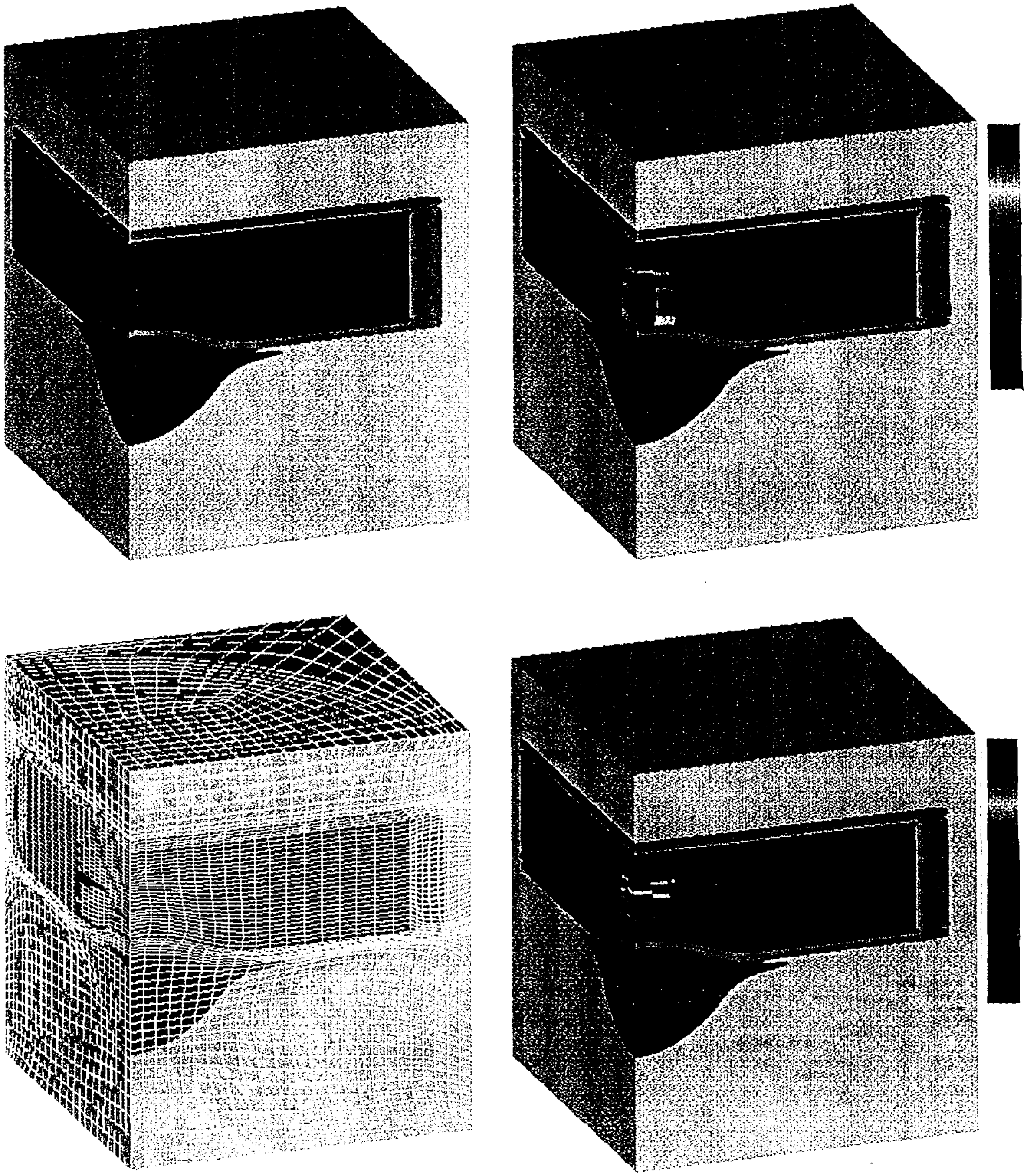

Figure 15: Initial projectile velocity 1.44 km/s at 35 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

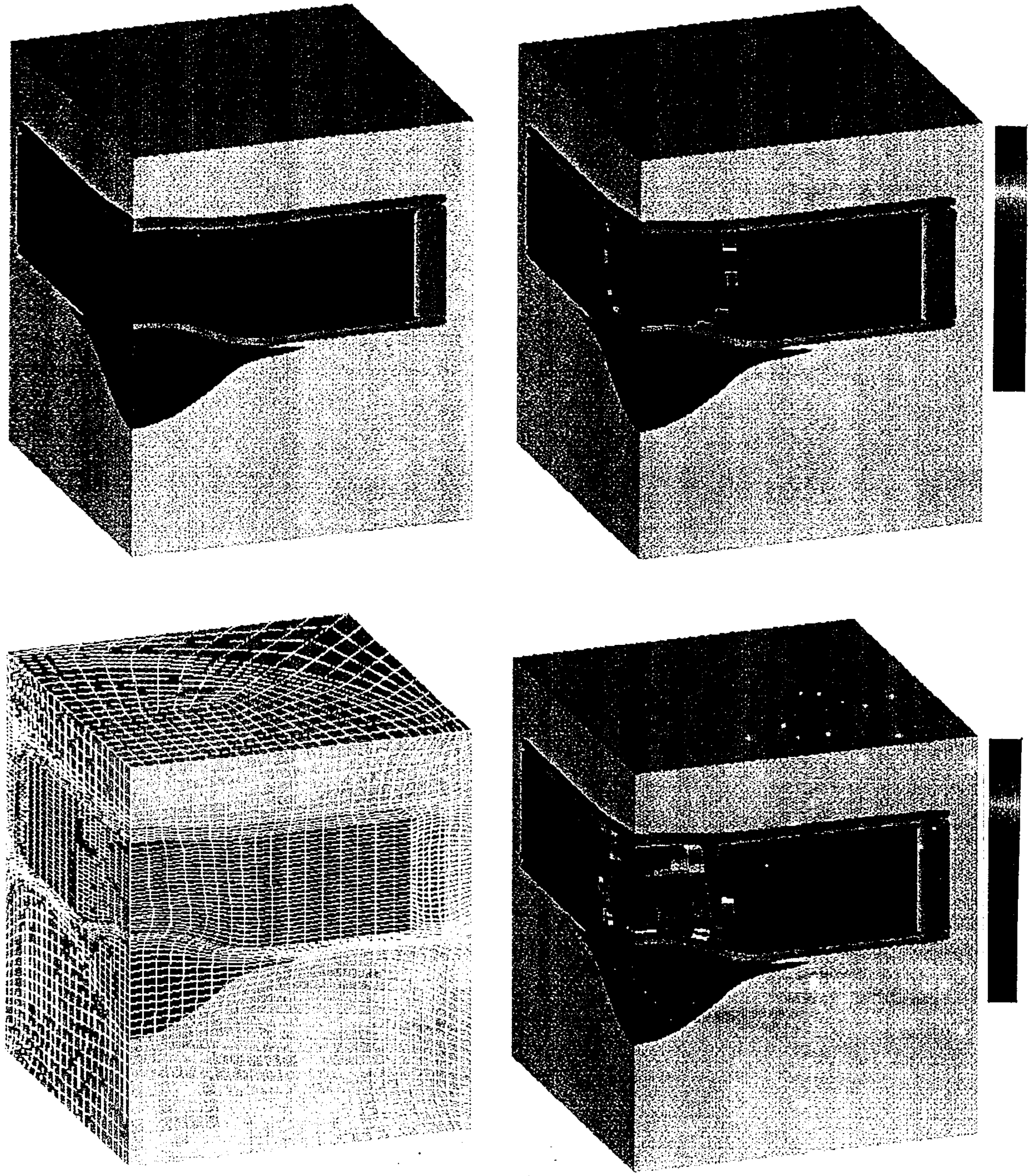

Figure 16: Initial projectile velocity 1.44 km/s at 40 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

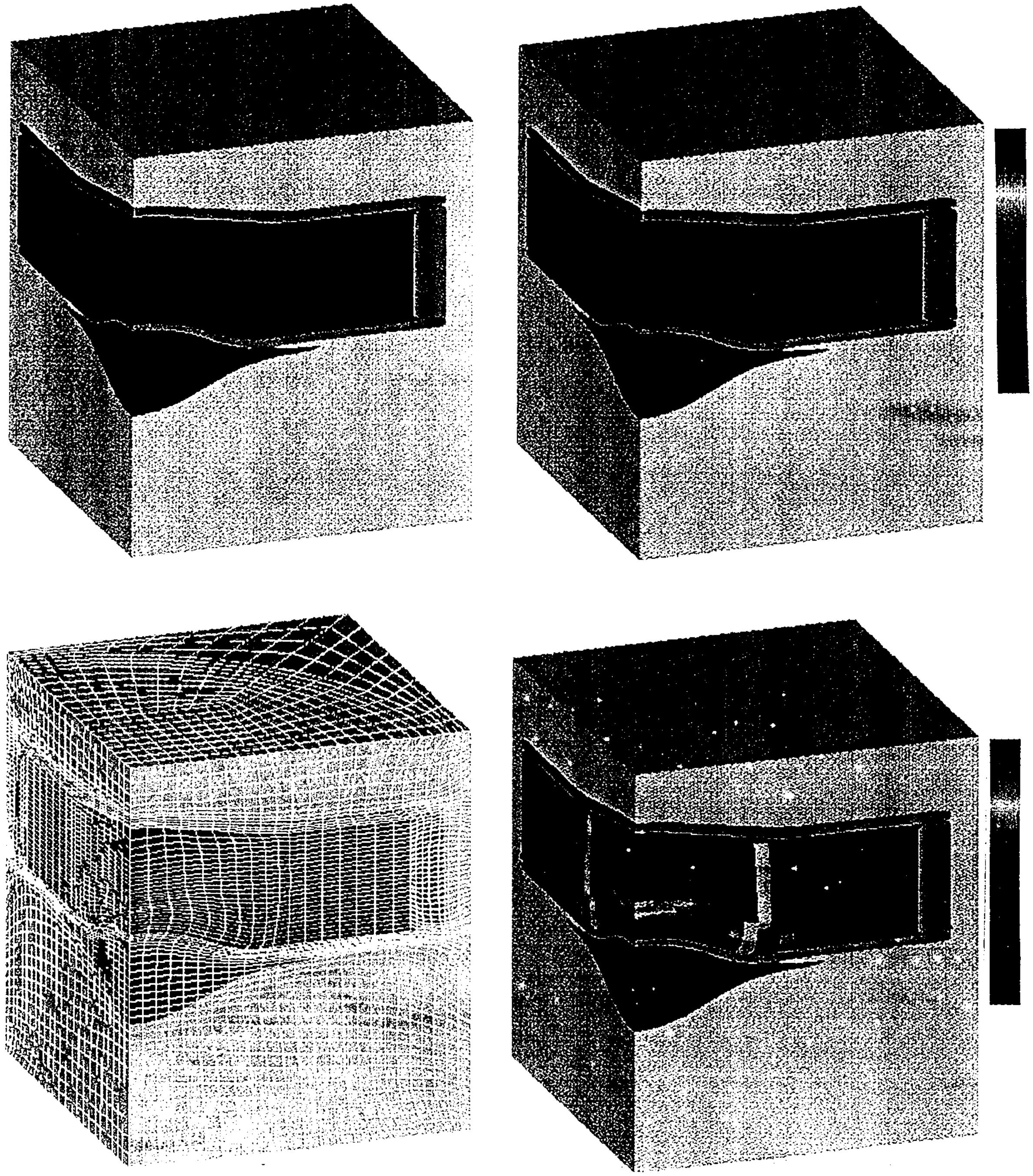

Figure 17: Initial projectile velocity 1.44 km/s at 45 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

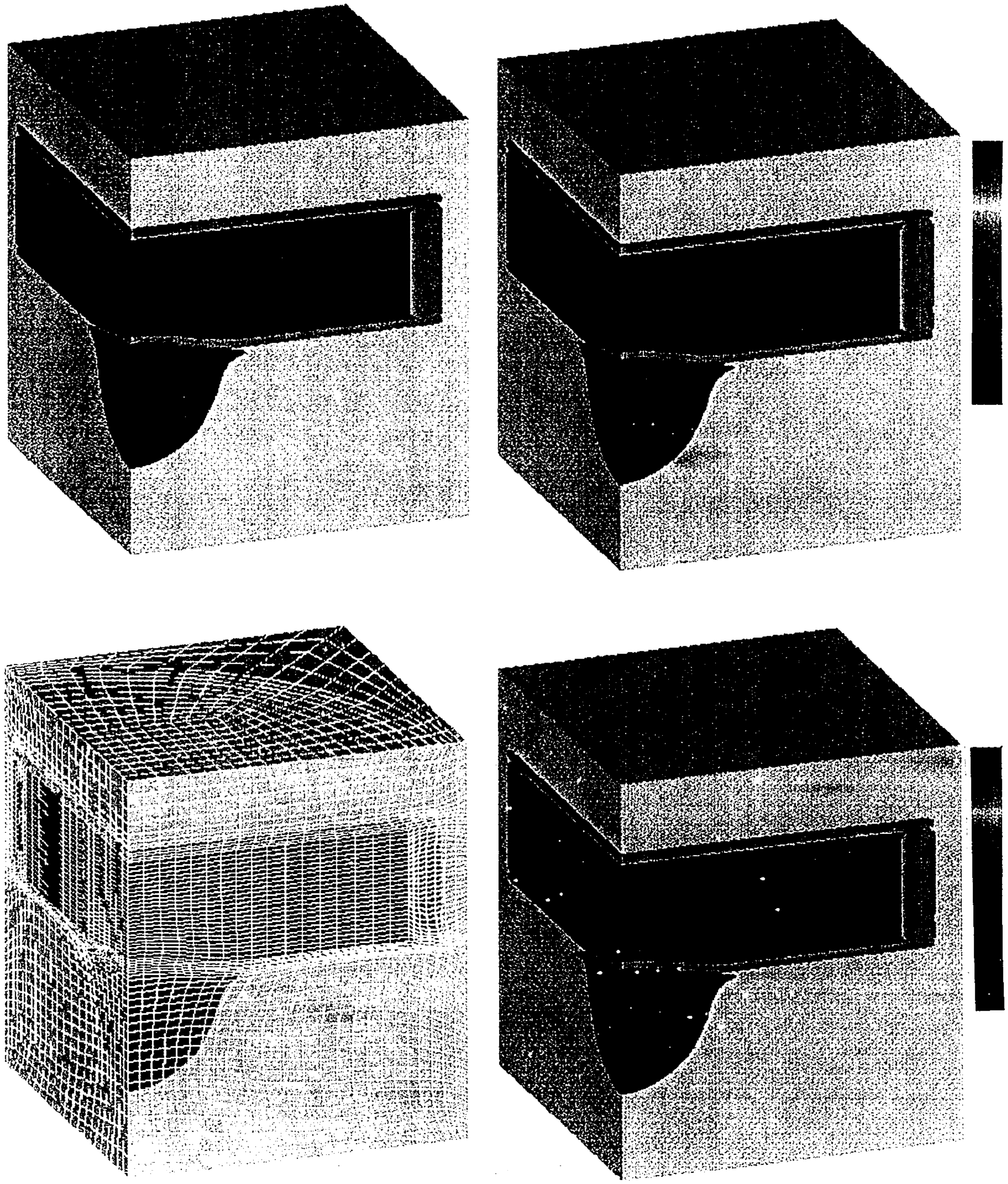

Figure 18: Initial projectile velocity 1.385 km/s at 25 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

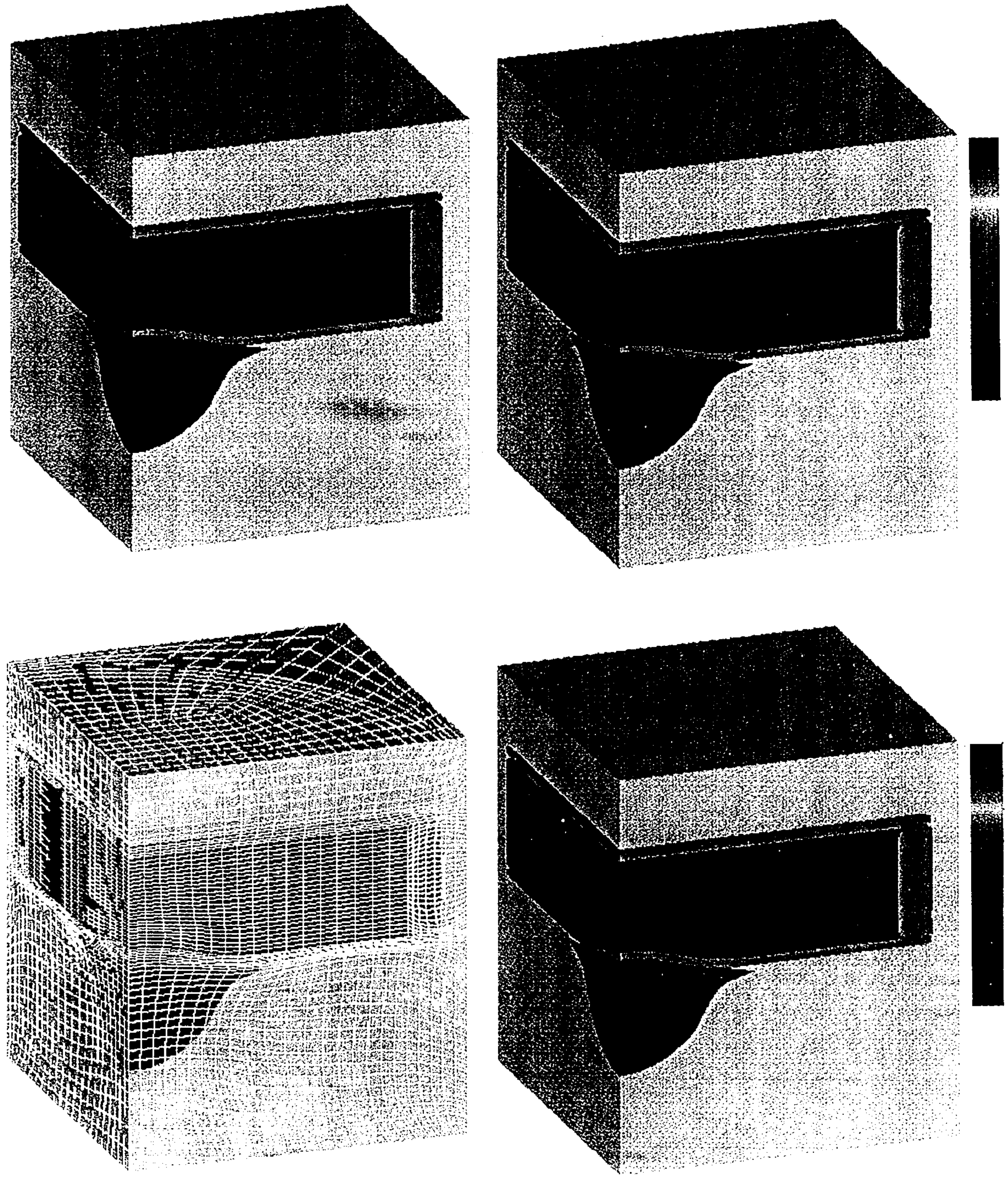

Figure 19: Initial projectile velocity 1.385 km/s at 30 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

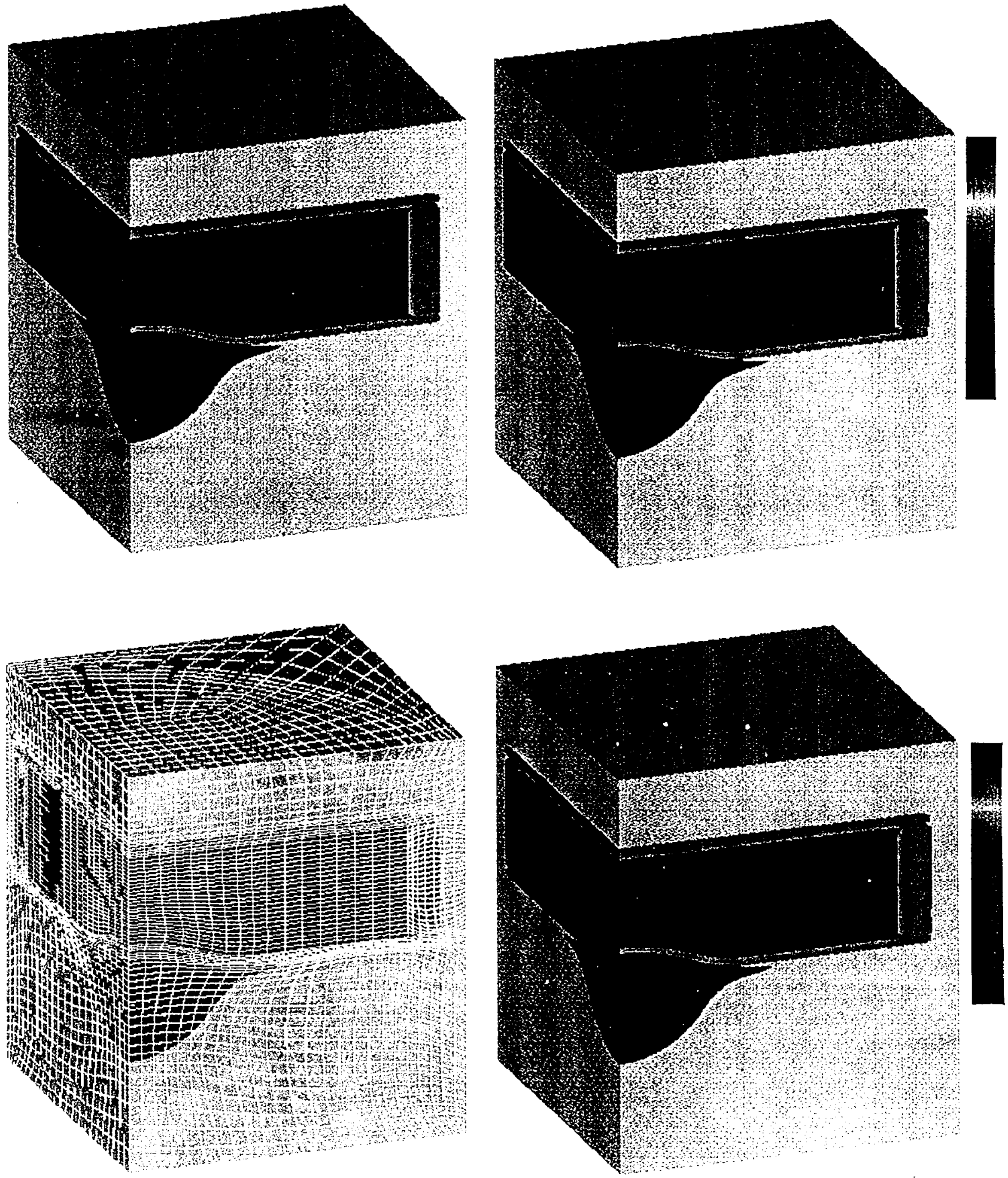

Figure 20: Initial projectile velocity 1.385 km/s at 35 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

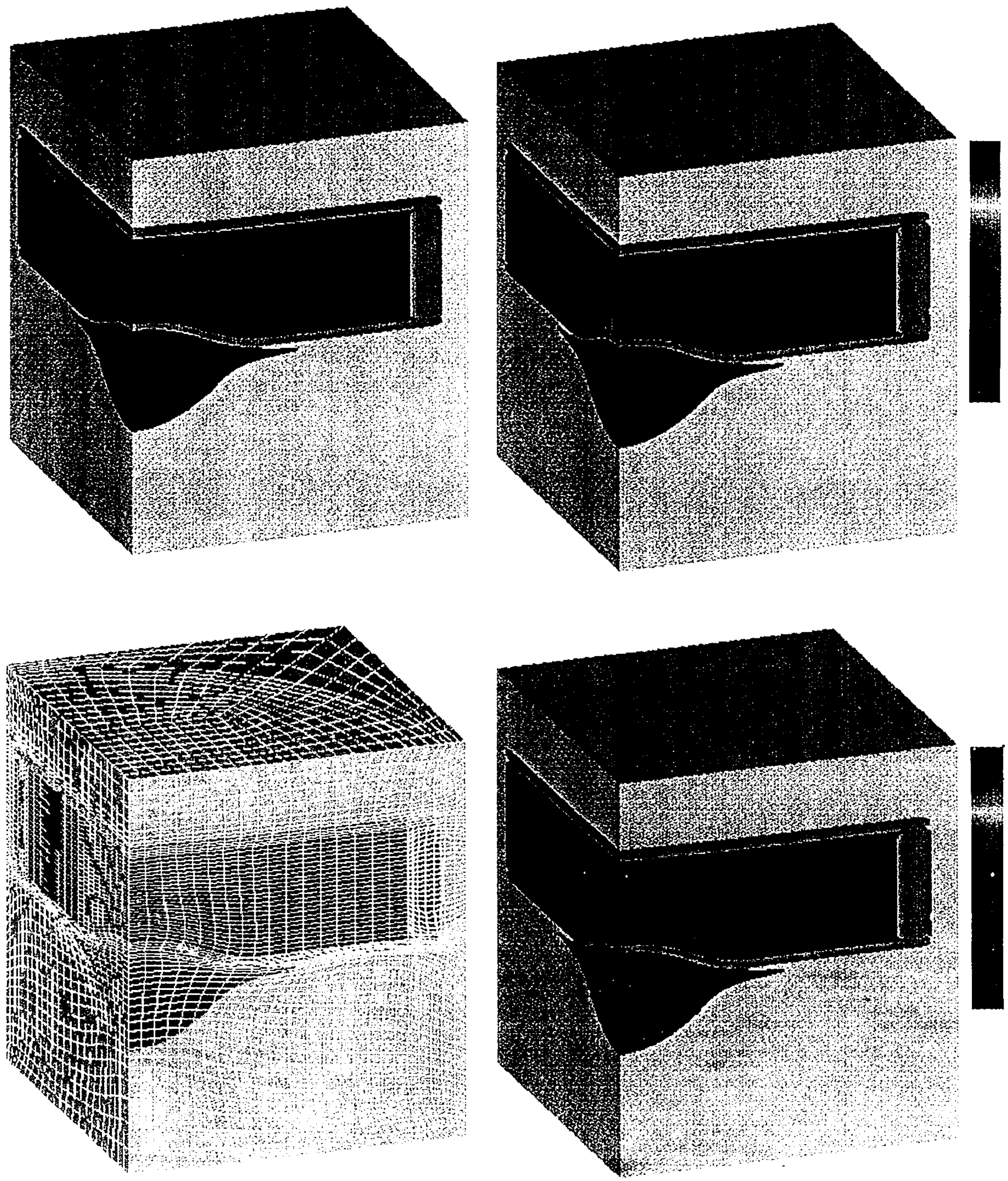

Figure 21: Initial projectile velocity 1.385 km/s at 40 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

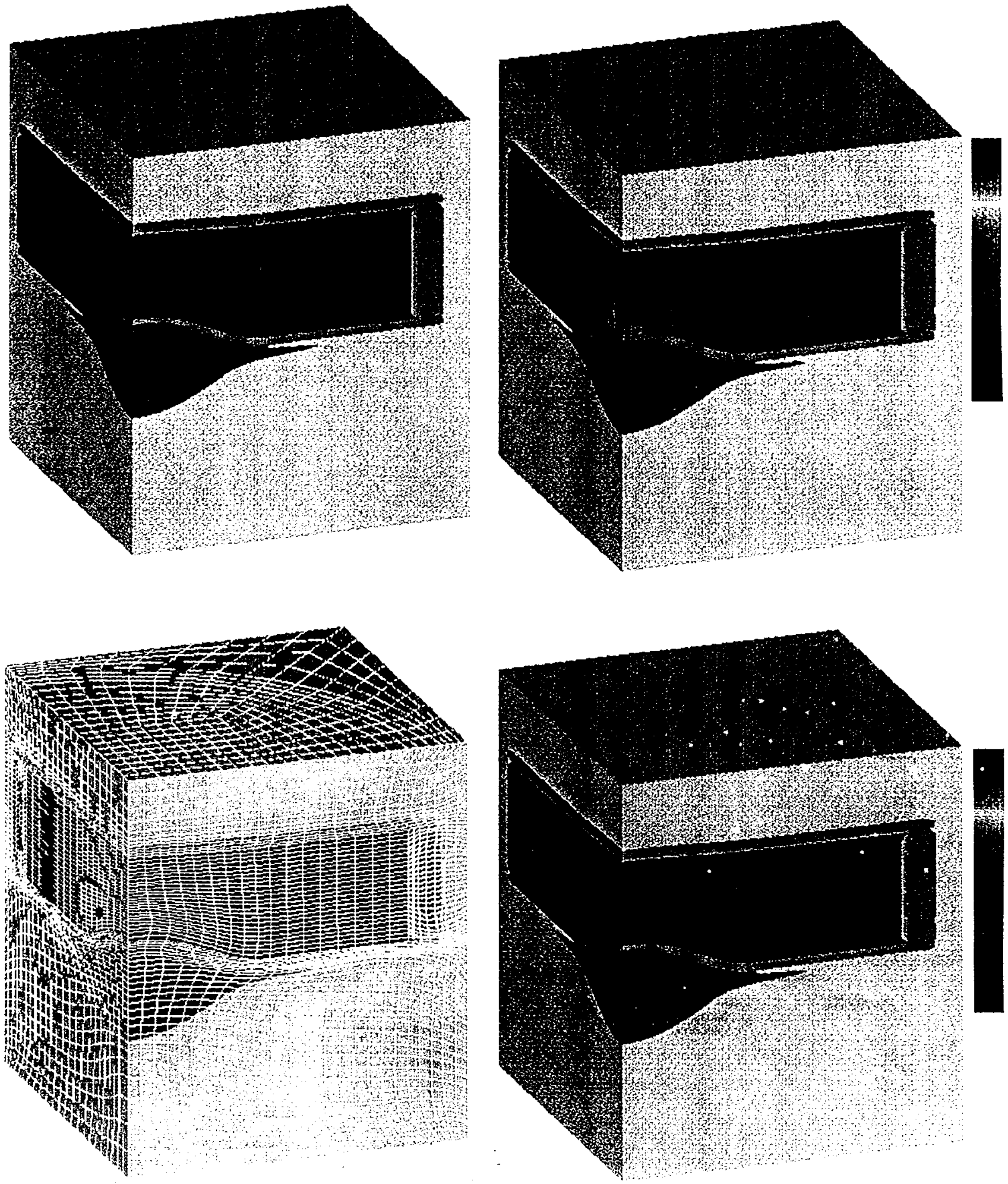

Figure 22: Initial projectile velocity 1.385 km/s at 45 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

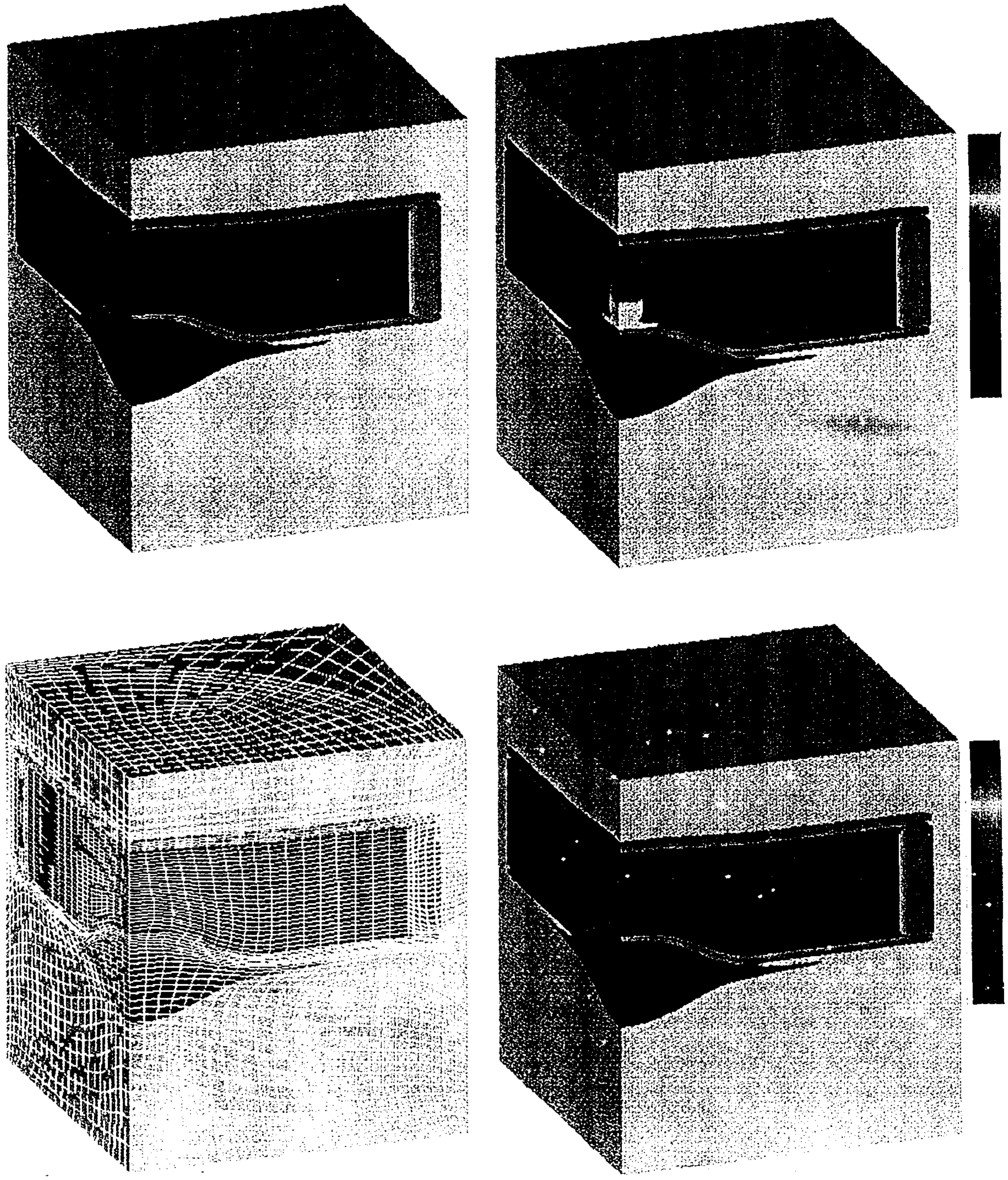

Figure 23: Initial projectile velocity 1.385 km/s at 50 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

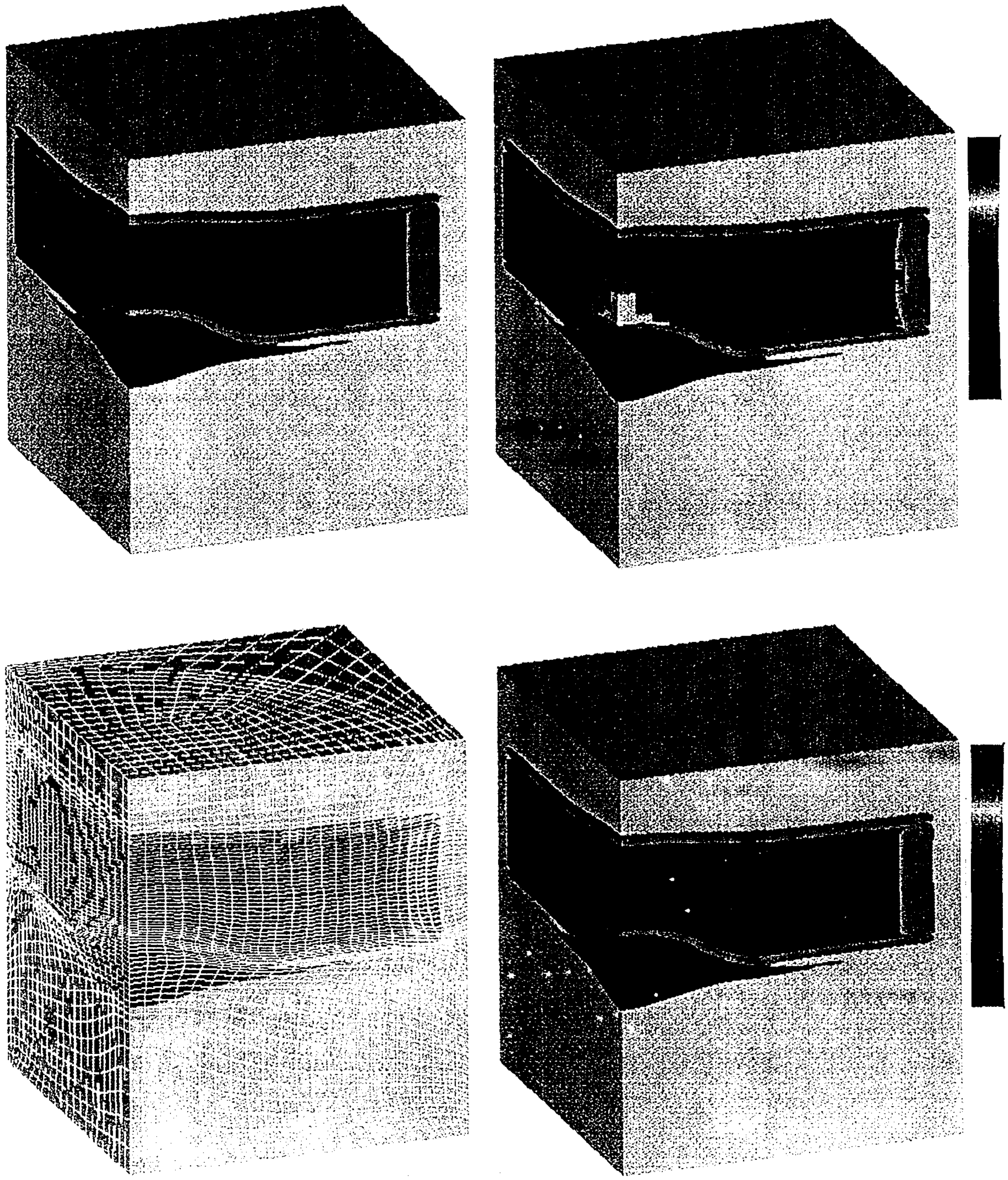

Figure 24: Initial projectile velocity 1.385 km/s at 60 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

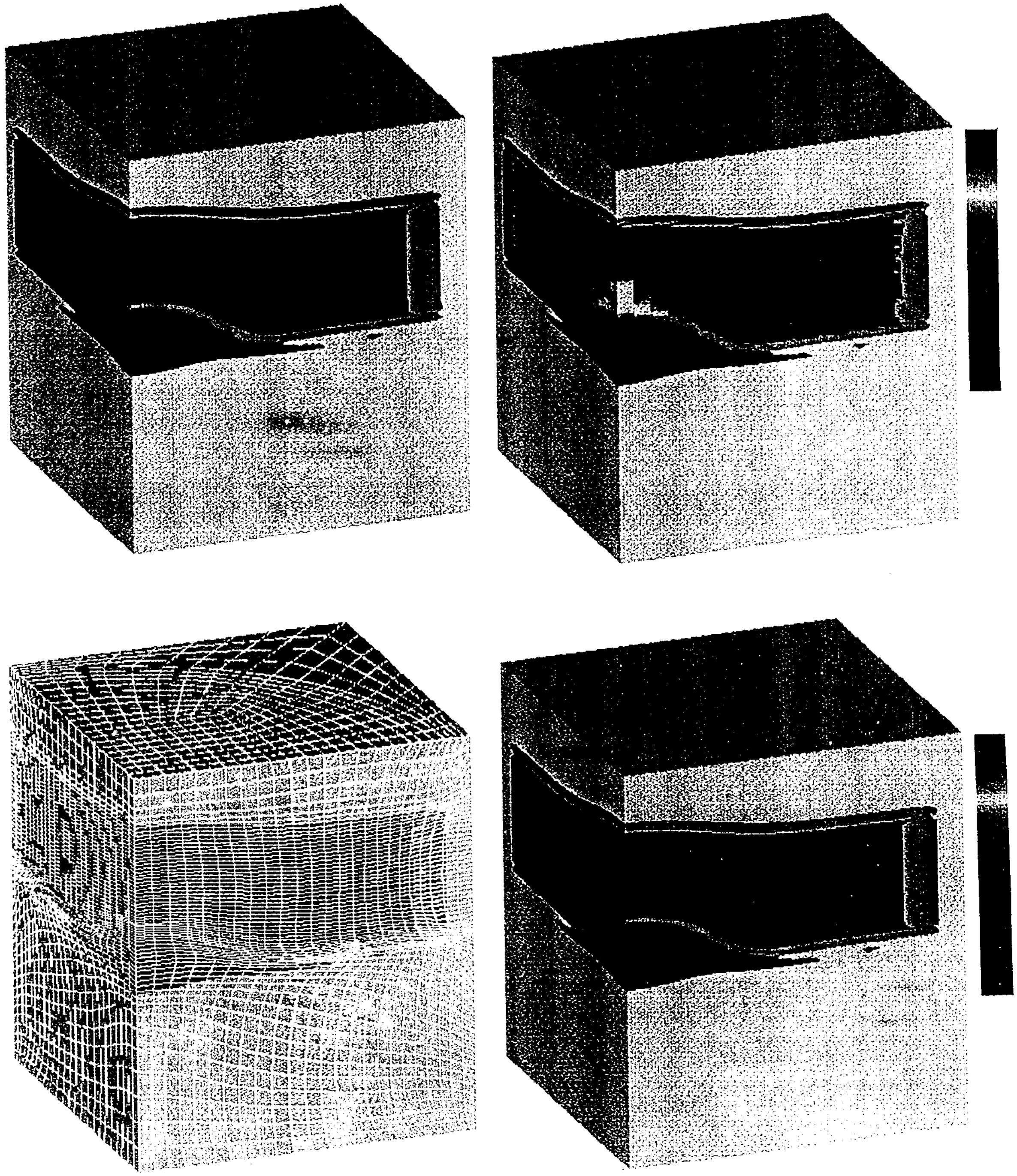

Figure 25: Initial projectile velocity 1.385 km/s at 70 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

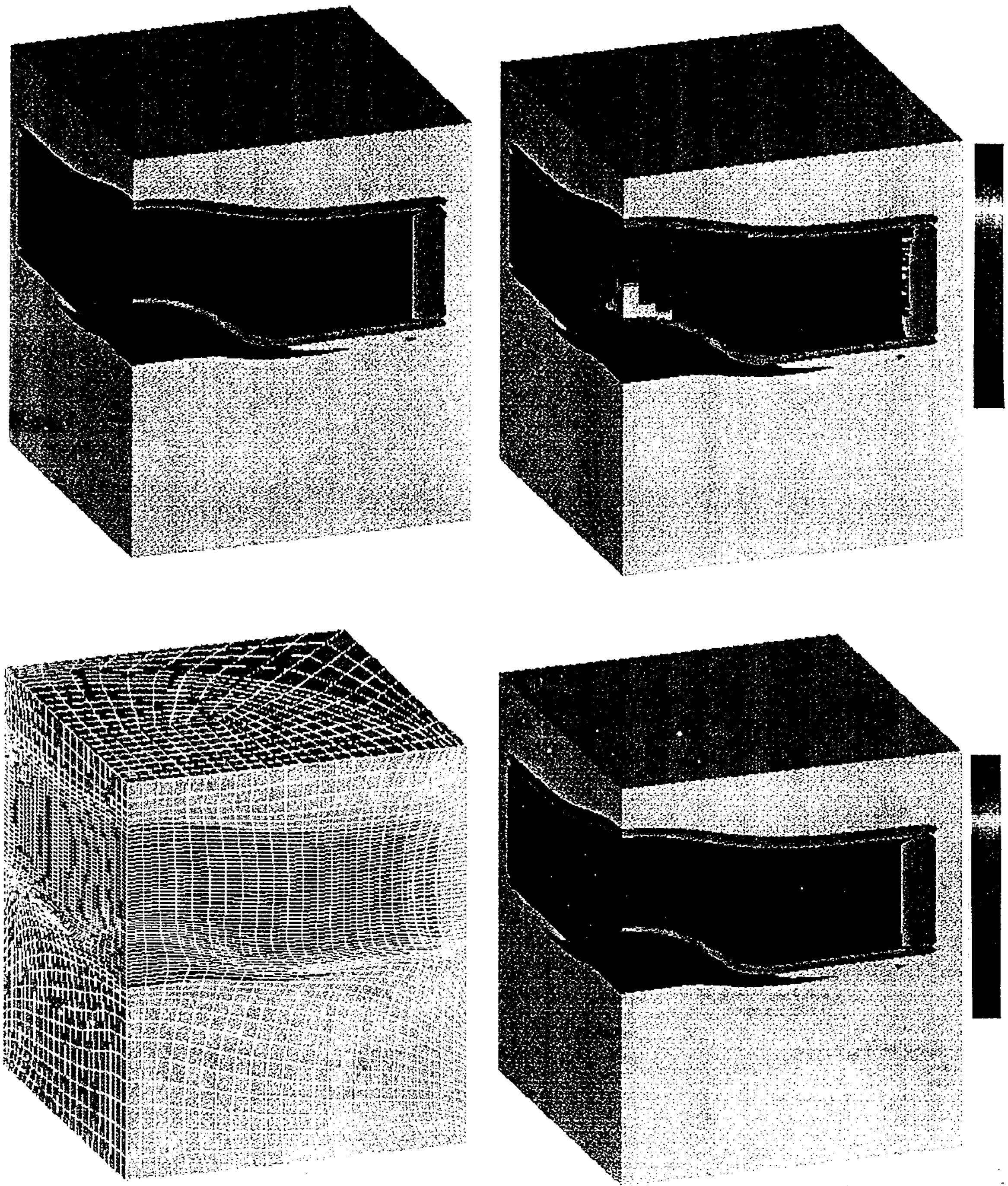

Figure 26: Initial projectile velocity 1.385 km/s at 80 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

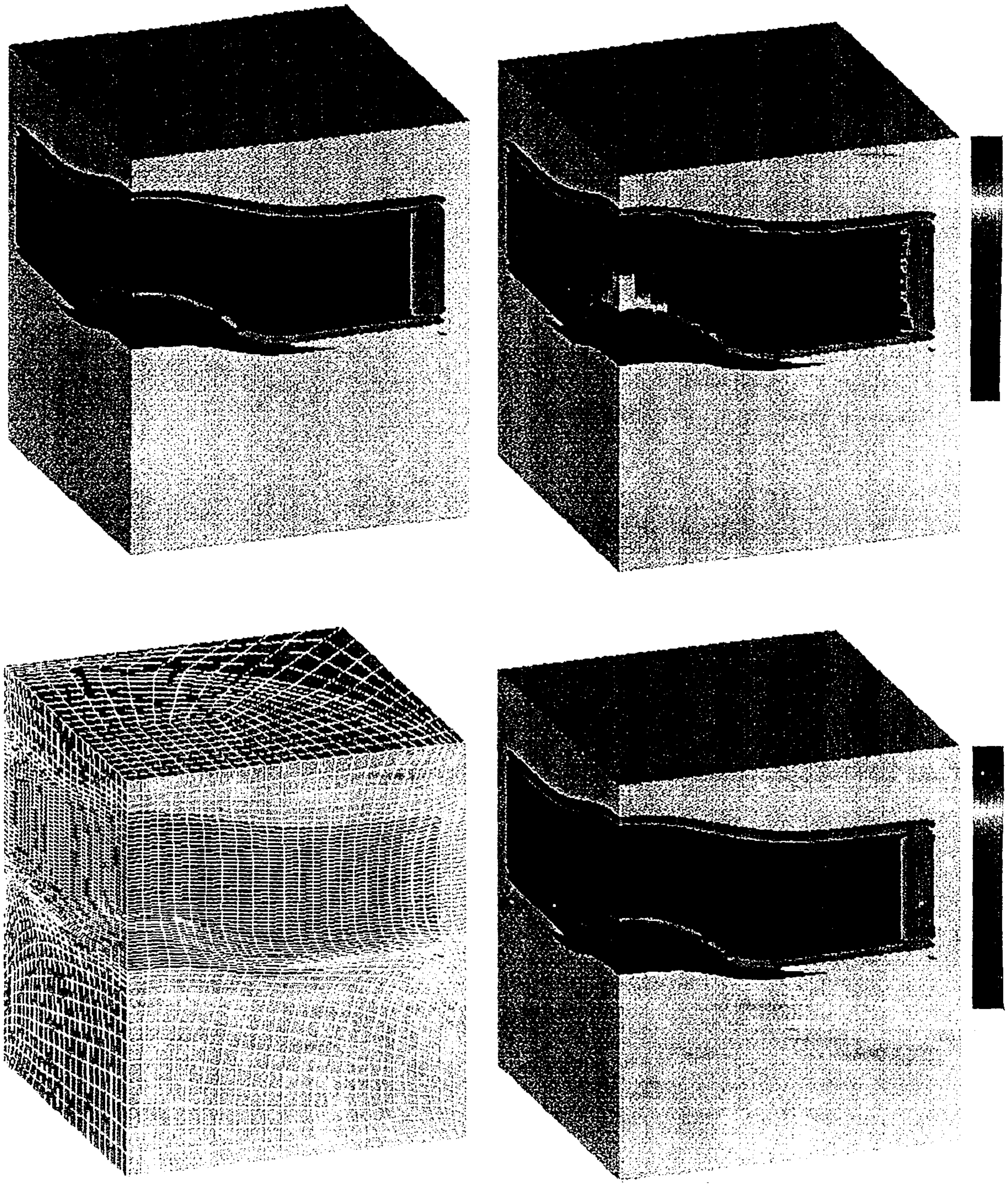

Figure 27: Initial projectile velocity 1.385 km/s at 90 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

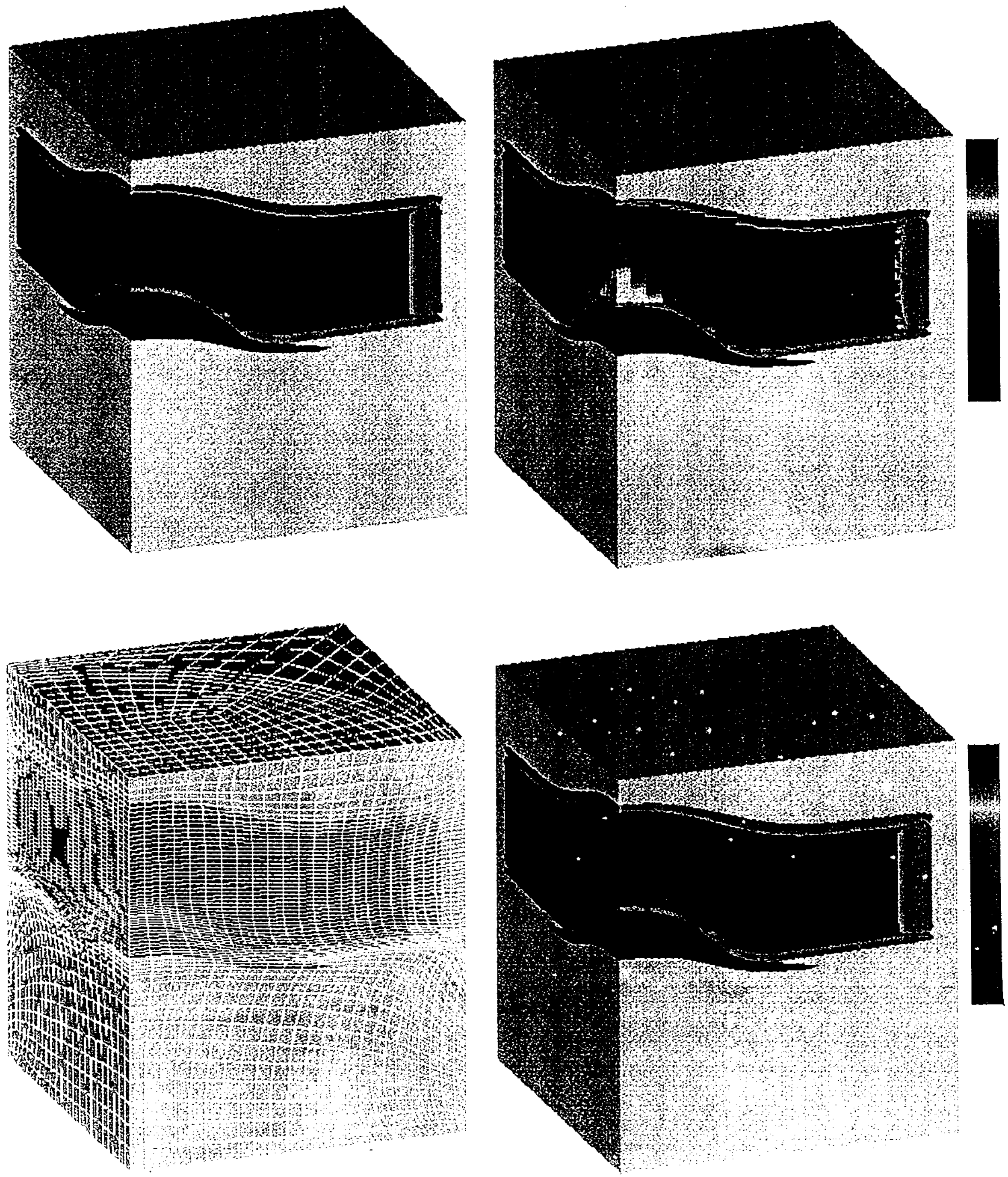

Figure 28: Initial projectile velocity 1.385 km/s at 100 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

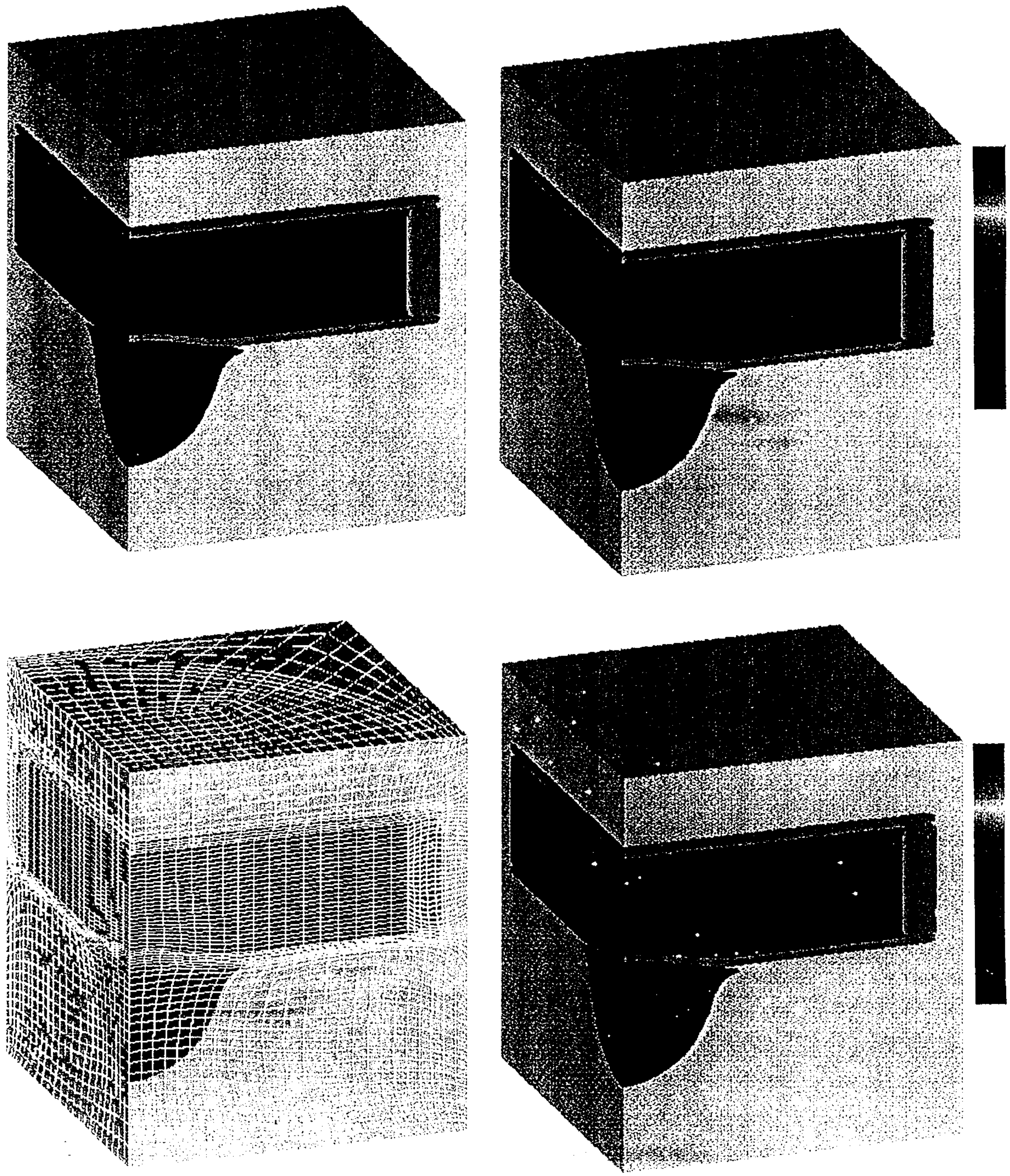

Figure 29: Initial projectile velocity 1.390 km/s at 25 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

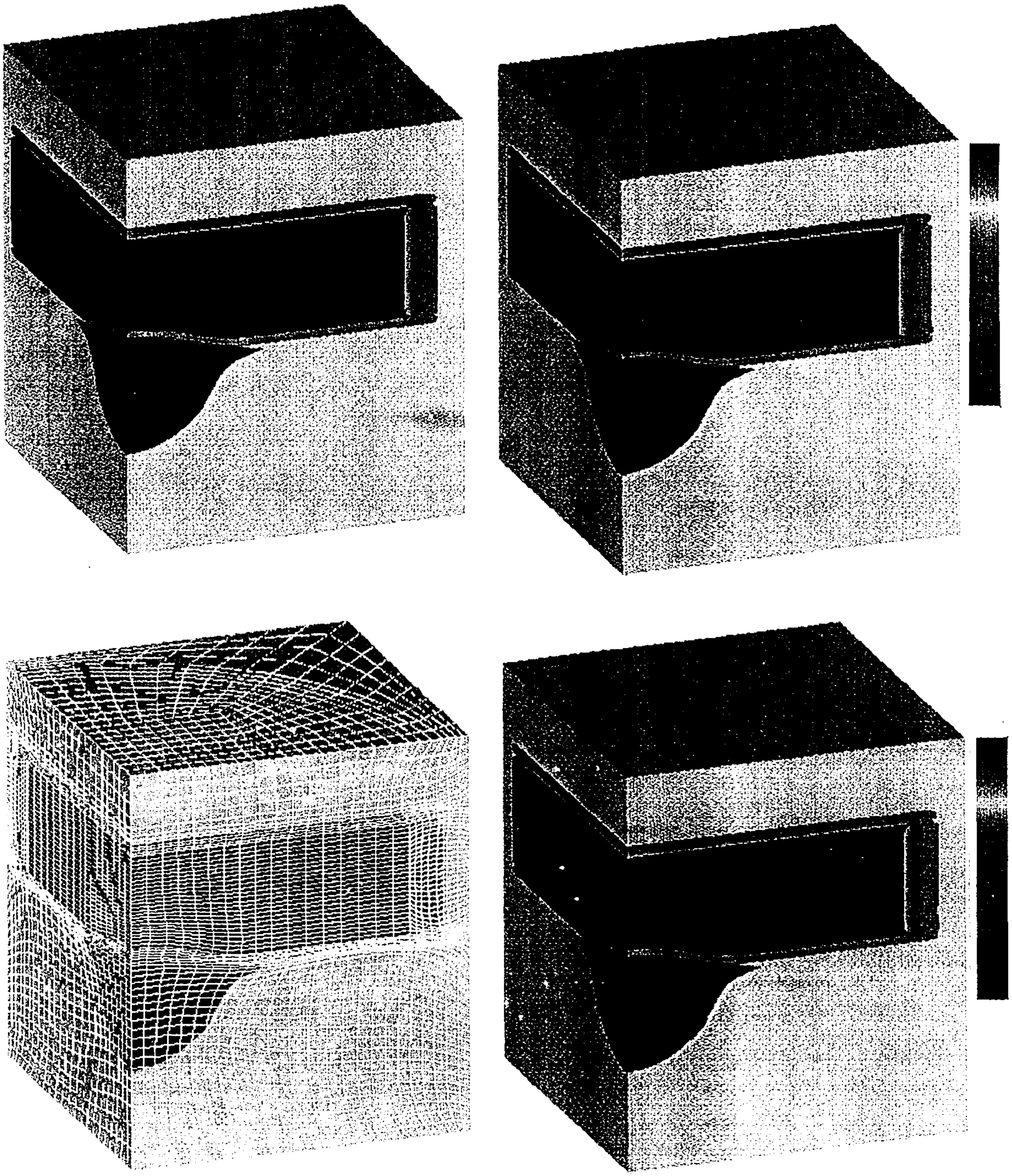

Figure 30: Initial projectile velocity 1.390 km/s at 30 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

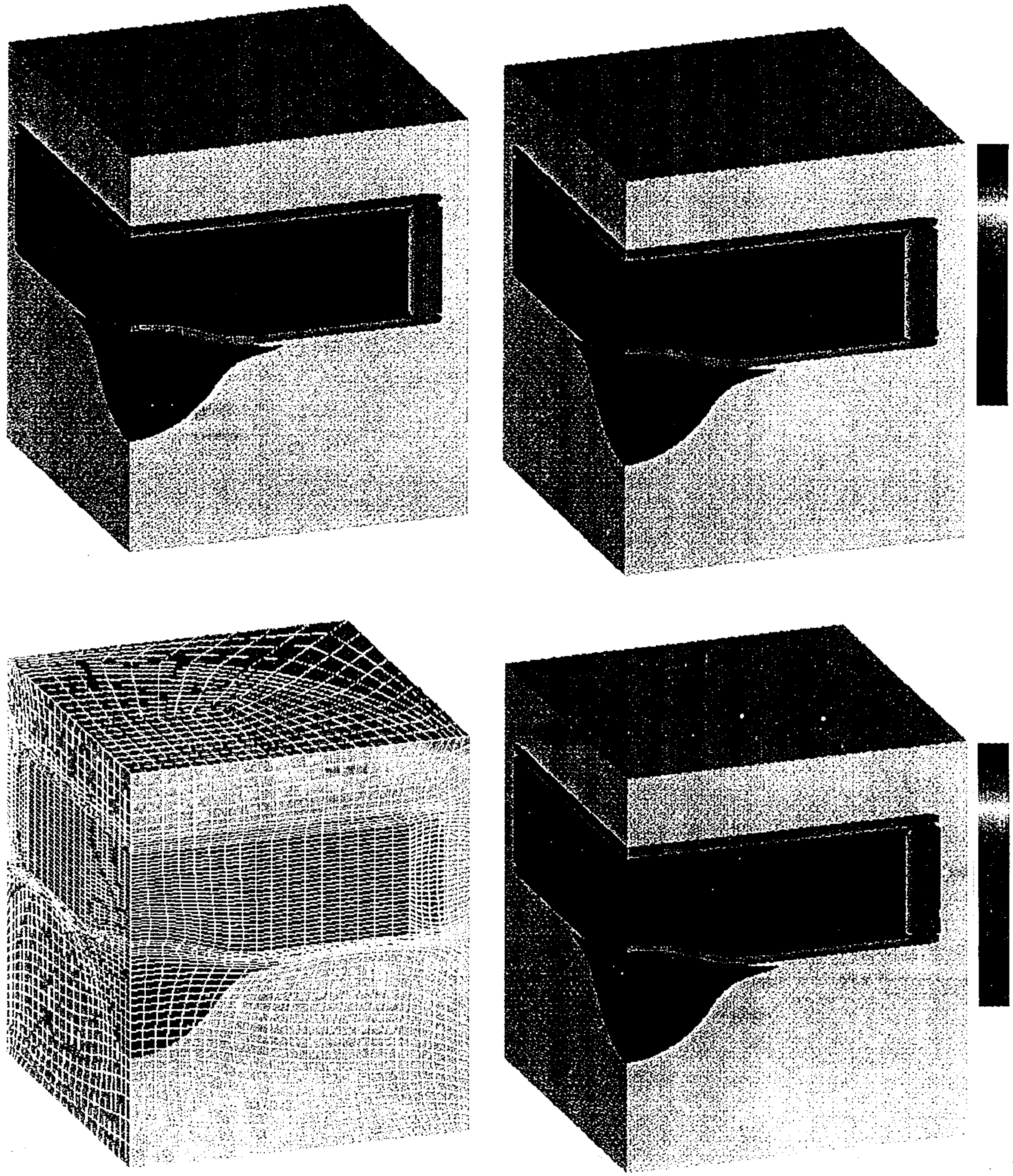

Figure 31: Initial projectile velocity 1.390 km/s at 35 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

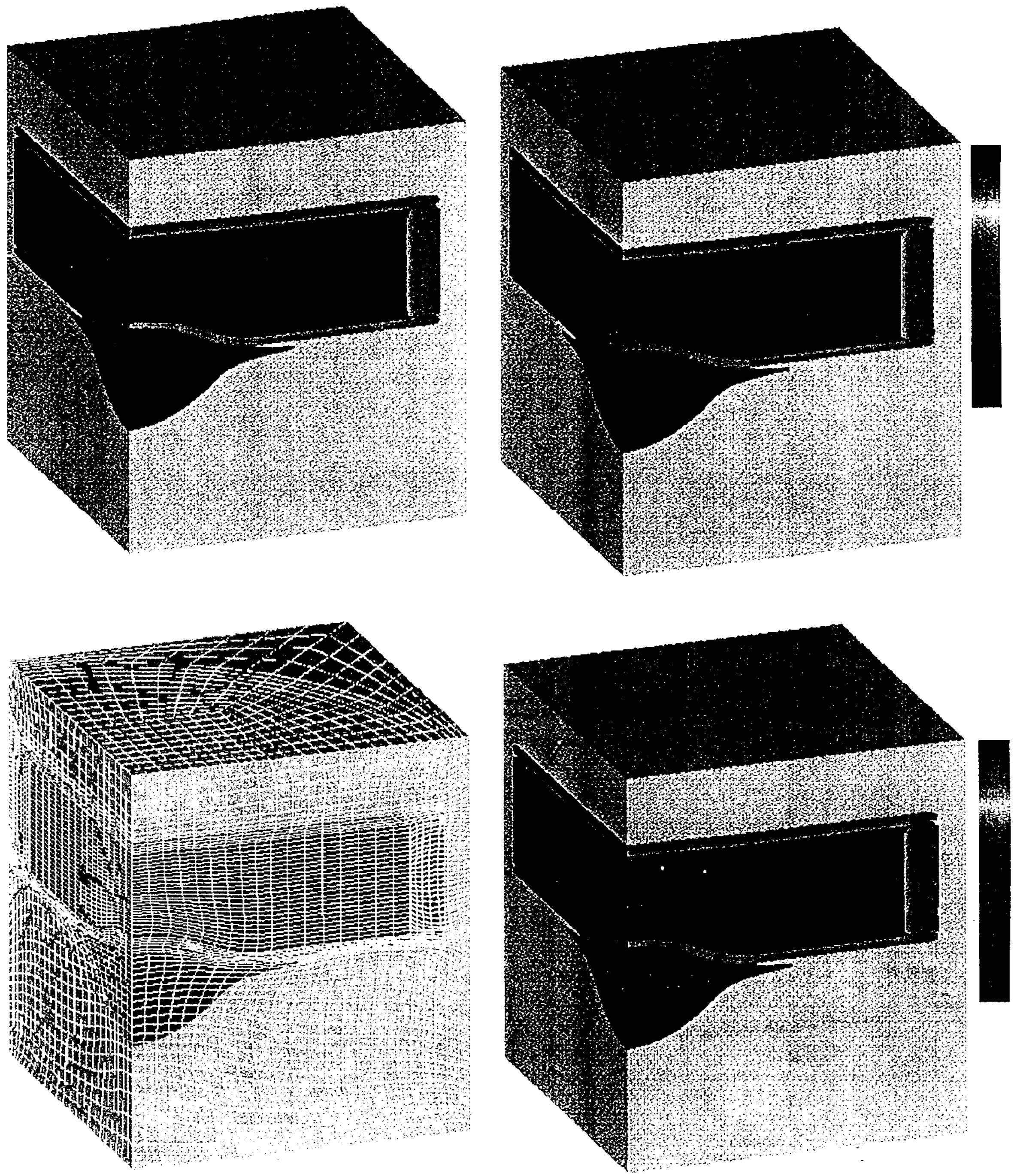

Figure 32: Initial projectile velocity 1.390 km/s at 40 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

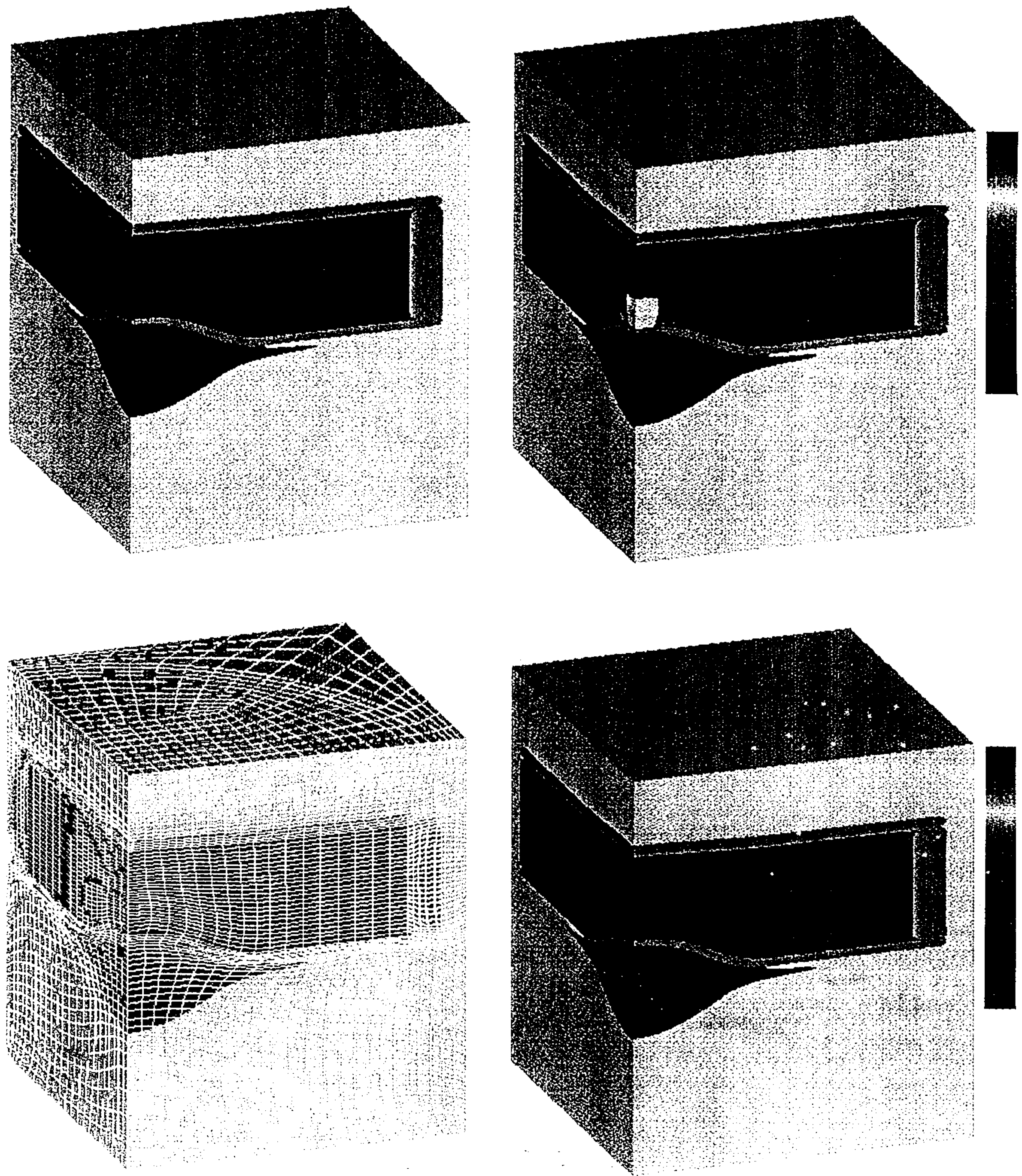

Figure 33: Initial projectile velocity 1.390 km/s at 45 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

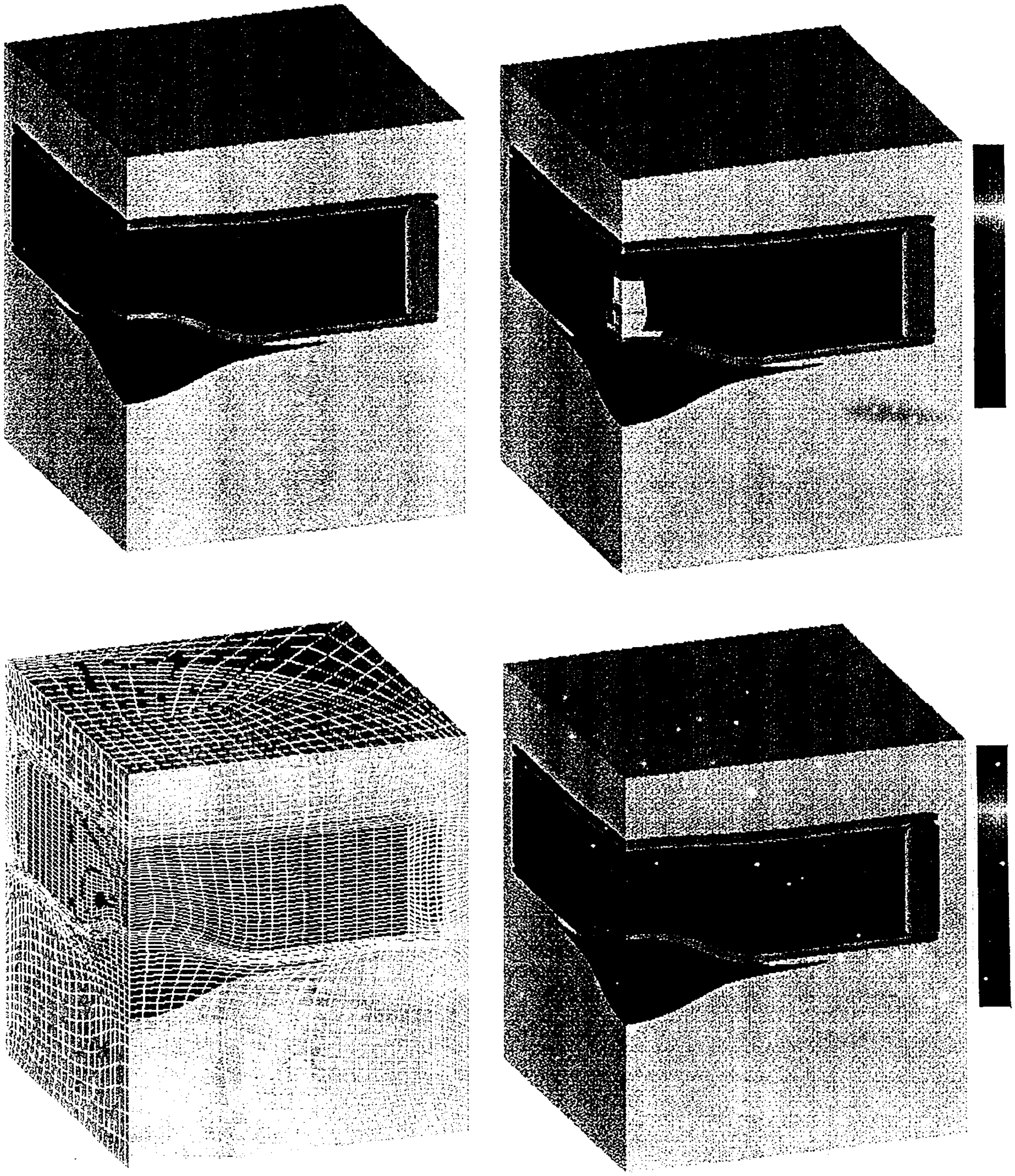

Figure 34: Initial projectile velocity 1.390 km/s at 50 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

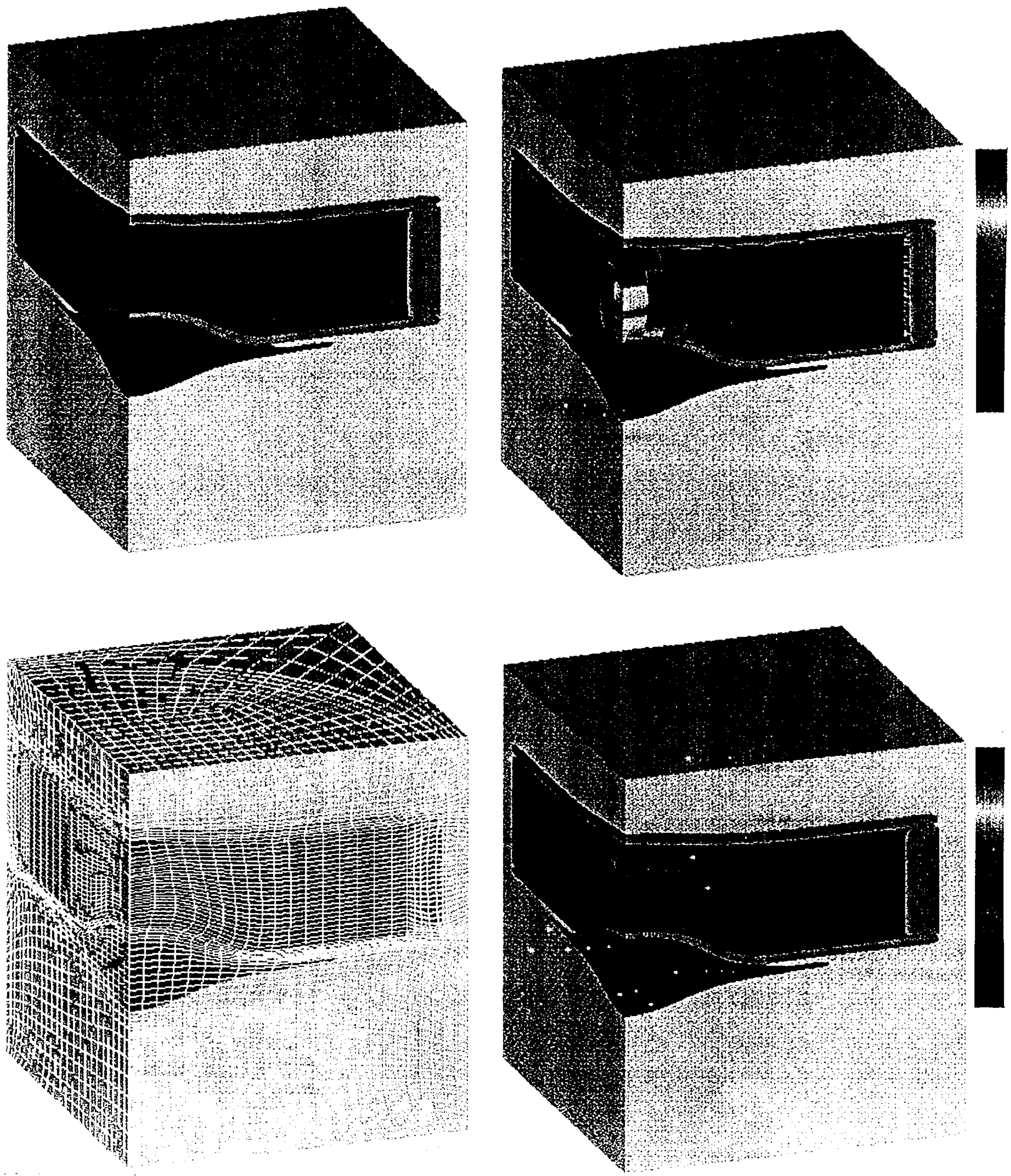

Figure 35: Initial projectile velocity 1.390 km/s at 55 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

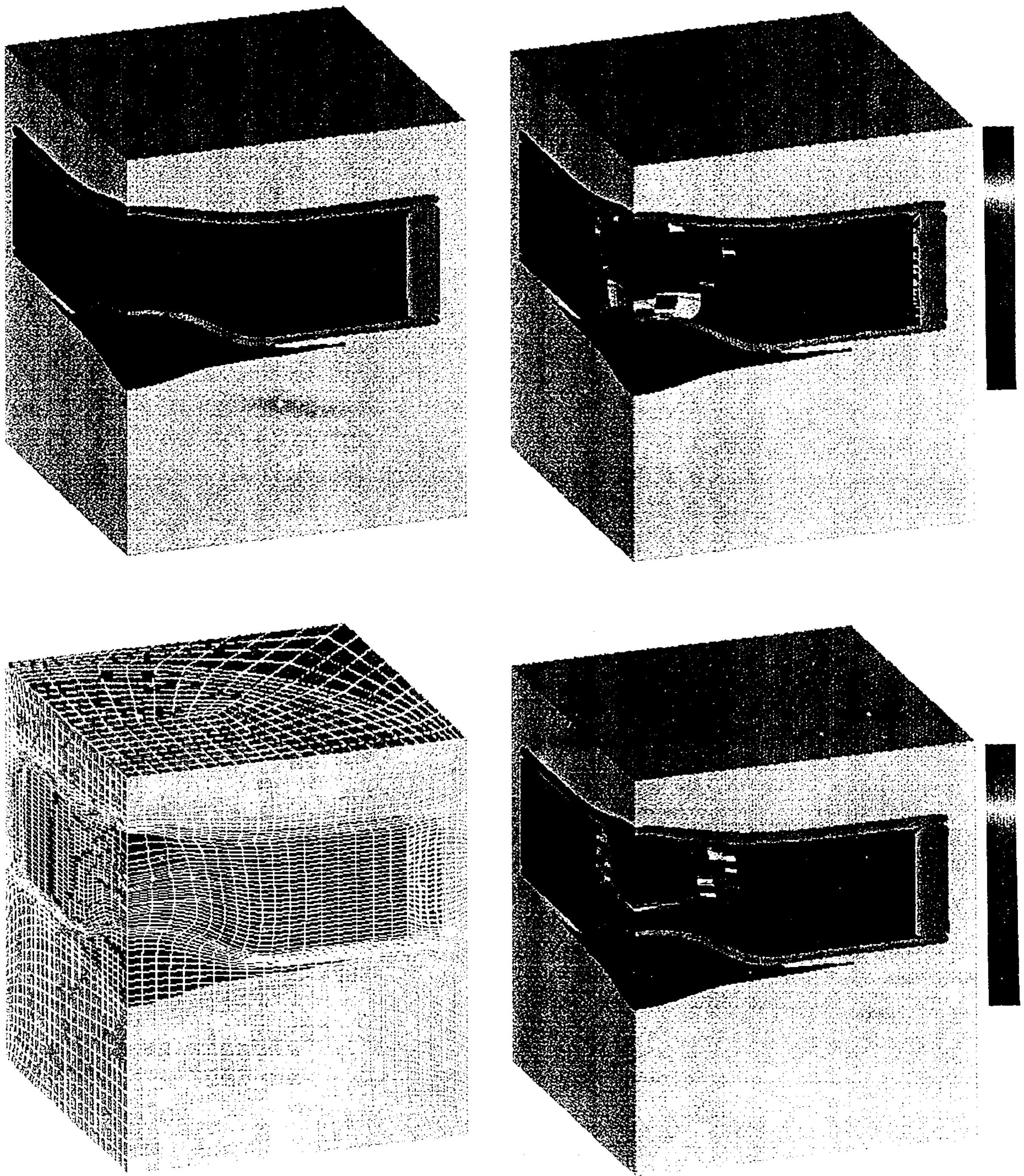

Figure 36: Initial projectile velocity 1.390 km/s at 60 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

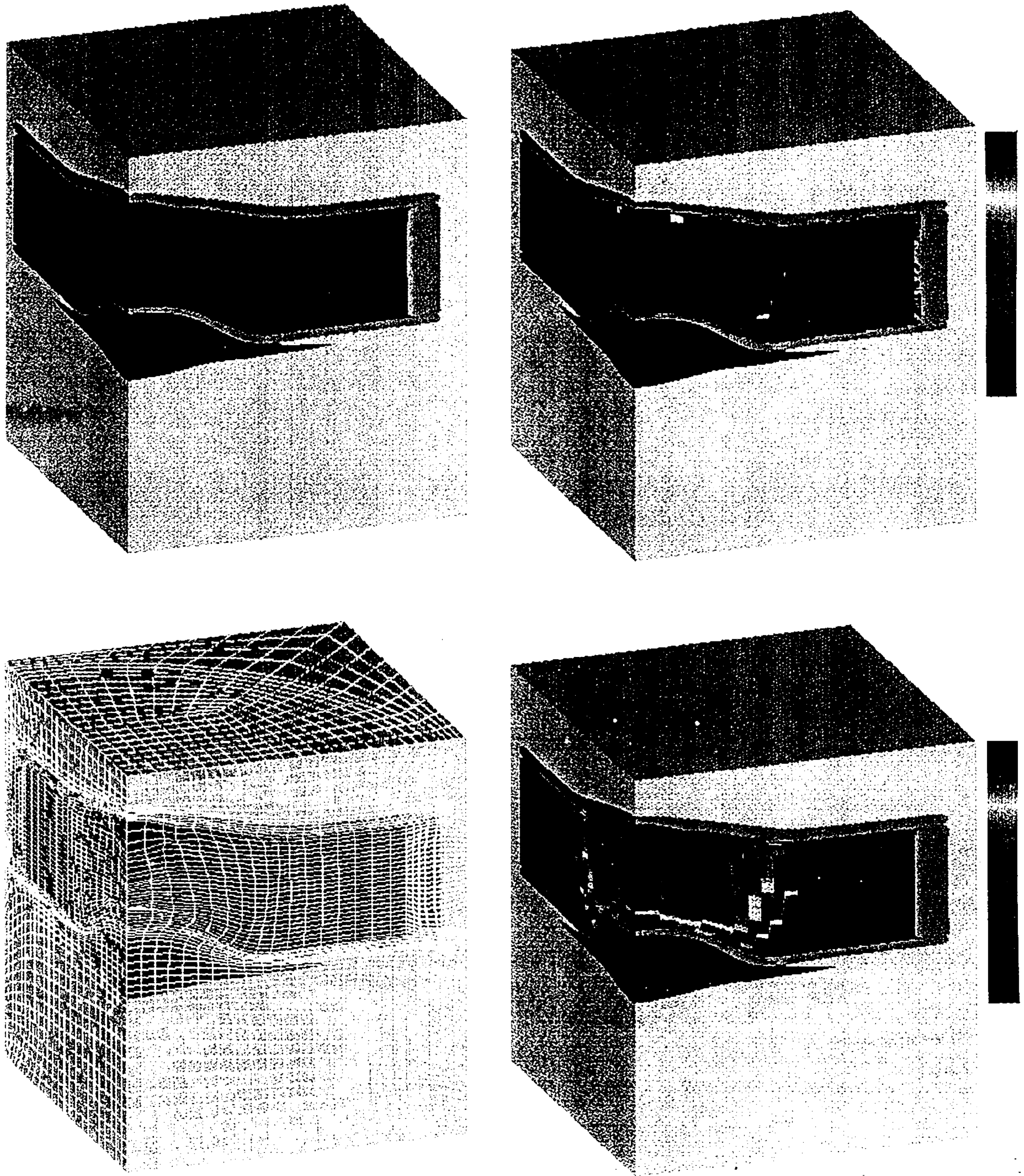

Figure 37: Initial projectile velocity 1.390 km/s at 65 μs. Materials maps with zoning (bottom left), reacted HE fraction (top right, scale of 0 to 1) and HE pressure (bottom right, scale of 0 to 100 kbar).

In the standard test problem calculations the HE is devoid of mixed zones until late in the calculation, long after projectile impact. In many calculations mixed zones are present from the very beginning. Versions of ALE3D up to 2.8.3 produced different detonation thresholds for the test problem depending on whether mixed zones were present in the HE at projectile impact. The detonation threshold was 7 to 8 percent higher when mixed zones were present. This was traced to inadvertent inhibition of HE burn in mixed zones and was remedied with version 2.8.18. We examine the effect of allowing mixed zones in the HE prior to projectile impact. Allowing mixed zones in the HE brings potential dependence of the IGM on whether pressure relaxation is turned on in mixed zones. The default setting in ALE3D is to have this relaxation turned off. The runs discussed in the previous section were carried out with the pressure relaxation in mixed zones turned off, but this has no effect on the calculation since the HE was made up of clean zones until late times. We have established that turning off pressure relaxation in mixed zones produces more accurate transport of lateral solid material momentum across a void or air, when coarse zoning is used. Platform limitations often force the use of coarse zoning in full scale impact calculations, so many problems are run with pressure relaxation in mixed zones turned off. We examine the effect of turning pressure relaxation in mixed zones on. Finally, the runs discussed in the previous section were carried out with the default value of rlxginit i.e. 0. This means that mesh relaxation was applied to the nodal positions at the end of the cycle. Many problems involving penetration of one material into others run better with rlxginit set to one which applies relaxation to the nodal positions at the beginning of the cycle. In our experience many runs that gets into trouble can be continued by changing the value of rlxginit. We examine the effect of rlxginit.

We carried out the sensitivity study by varying the projectile velocity by 0.005 km/s until we found runs that just produce detonation and others that are just short of it. The results are shown in Table 1. They are heartening, given that the detonation threshold varies by 2.5% across the entire space. There is very little dependence on whether mixed zones are present in the HE at projectile impact, little dependence on turning pressure relaxation off, and little dependence on rlxginit.

Table 1

Dependence of HE behavior on model initial conditions

Initially clean zones in HE rlxginit=0	V = 1.385 km/s V = 1.390 km/s	Insignificant HE reaction at 100 μs Detonation at 60 μs
Initially clean zones in HE rlxginit=1	V = 1.395 km/s V = 1.400 km/s	Insignificant HE reaction at 100 μs Detonation at 55 μs
Mixed zones in HE Pressure relaxation off rlxginit=0	V = 1.370 km/s V = 1.375 km/s	Insignificant HE reaction at 100 μs Detonation at 60 μs
Mixed zones in HE Pressure relaxation off rlxginit=1	V = 1.360 km/s V = 1.365 km/s	Insignificant HE reaction at 100 μs Detonation at 45 μs
Mixed zones in HE Pressure relaxation on rlxginit=0	V = 1.380 km/s V = 1.385 km/s	Insignificant HE reaction at 100 μs Detonation at 50 μs
Mixed zones in HE Pressure relaxation on rlxginit=1	V = 1.380 km/s V = 1.385 km/s	Insignificant HE reaction at 100 μs Detonation at 55 μs

rlxginit = 0 default setting, relaxation starting point is node position at end of cycle.

rlxginit = 1 relaxation starting point is node position at beginning of cycle.

Pressure relaxation on : default setting, materials in mixed zones forced to same pressure.

Pressure relaxation off : materials in mixed zones allowed to remain at different pressures.

Comparison with CALE

The original CALE calculations modeling the experiments were performed with much finer zoning than that used in our test problems. We performed CALE runs with zoning essentially identical to that used in the test problems. In CALE pressure relaxation is always on, but this should have no effect since the HE is devoid of mixed zones. A run with 1.380 km/s initial projectile velocity produces HE burn which dies down to the point where insignificant HE reaction takes place at 100 μs. A run with 1.385 initial projectile velocity results in a detonation at 60 μs. This is in excellent agreement with the ALE3D runs reported above.

Test Problems Input

The true grid mesh generator input and the ALE3D inputs are listed in the appendix.

References

1. Lee, E.L. and Tarver, C.M., "Phenomenological Model of Shock Initiation in Heterogeneous Explosives," Phys. Fluids, Vol. 23, Nov. 12, 1980, pp 2362-2372.

2. Murphy, M.J., Lee, E.L., Weston, A.M. and Williams, A.E., "Modeling Shock Initiation in Composition B", 10^{th} Symposium on Detonation, ONR33395-12, 1993m pp 963-970.

3. Gerassimenko, M. and Otero, I., "Validation of Reactive Flow HE Model in the ALE3D Code", DDV-94-0042, 1994.

APPENDIX

```
title  mg HE initiation test problem mesh
ale3d
c initial mesh gives clean zones in HE
c and surrounding materials
plane 1 0.0 0.0 0.2 1.0 0.0 0.0 0.01 symm ;
plane 2 0.0 0.0 0.2 0.0 1.0 0.0 0.01 symm ;
block
1 5 8 17 26 29 33;
1 5 8 17 26 29 33;
1 23 26 51 54 62;
-15.2 -15.2 -15.2 0.0 15.2 15.2 15.2
-15.2 -15.2 -15.2 0.0 15.2 15.2 15.2
0.2 9.0 9.37 14.37 14.9 18.0
dei 1 3 0 5 7; 1 3 0 5 7; ;
sfi -3 -5; -3 -5; ; cy 0.0 0.0 0.0 0.0 0.0 1.0 12.5
sfi -2 -6; -2 -6; ; cy 0.0 0.0 0.0 0.0 0.0 1.0 14.0
de 3 3 0 5 5 0
de 1 0 0 4 0 0
de 0 1 0 0 4 0
c background air
mate 6
endpart
block
1 9 18 27 35;
1 9 18 27 35;
1 23 26 51 54 62;
-6.2 -6.2 0.0 6.2 6.2
-6.2 -6.2 0.0 6.2 6.2
0.2 9.0 9.37 14.37 14.9 18.0
dei 1 2 0 4 5;1 2 0 4 5; ;
sfi -1 -5; -1 -5; ; cy 0.0 0.0 0.0 0.0 0.0 1.0 12.5
de 1 0 0 3 0 0
de 0 1 0 0 3 0
mate 6
endpart
tolerance 0.01
merge

interrupt

continue
```

```
# tp1
# test problem for reactive flow HE initiation
# 1.38km/sec HE burn that dies out
############################
OUTPUT
nodeset vel_ints material  1
nodeset frees freesurface
restartvar default
#
plotac 1
stoptime 100.
dumpcycle 1 2 100 2000
dumptime 5.0 100.
plotcycle 1 2 100 2000
plottime  5.0 100.
table t1 0.0 1.0 1000.0 1.0
#
END
#####################################
# CONTROL parameter block
######################################################
CONTROL
# set timelimit for run in minutes
timelimit 1200
msgorder 1
ssvfcut .1
notify 1
dtinit 1.e-3
dtmax 1.0
dtmin 1.e-9
END
#########################################################
# HYDRO parameter block
#########################################################
HYDRO
# turn off pressure relaxation in mixed zones
presseq 0
qstop 1.e6
END
#########################################################
# ADVECTION parameter block
#########################################################
ADVECTION
advcycle 1
# relax zones into material prior to running analysis
advitercnt 50
ATCYCLE 3 advitercnt 1
advdtcon .2
ATCYCLE 3 advdtcon 0.1
rlxumin 0.0
rlxwprop 2
advpfmr 0.1
fracke 1
# sometimes best to relax mesh from initial configuration
# rlxginit 1
advdvmax 0.99
rlxmethod equipotential
# 3 materials in mixed zone = end of run, so prevent it
cvfcutx 1.0e-6
END
```

```
############################################################
# BOUNDARY parameter block
############################################################
BOUNDARY
# 1.38km/sec produces weak burn, 1.44km/sec detonation
VELOCITY vel_ints 0.0 0. 0.138
outflow  frees
pres_loadcurve frees  1.0e-6 table t1
END
############################################################
# SHAPE parameter block
############################################################
SHAPE
* Lexan projectile
 sphr  1  3.8  0.0 0.0 4.4
 shap  1 1
* Ta front plate
 cyl1  2 14.0  0.0 0.0 9.0  0.0 0.0 9.37
 shap  2 2
* Al outer ring
 cyl1  3 14.0  0.0 0.0 9.37 0.0 0.0 14.37
 shap  3 4
* HE cylinder
 cyl1  4 12.5  0.0 0.0 9.37 0.0 0.0 14.37
 shap  4 3
* Steel back plate
 cyl1  5 14.0  0.0 0.0 14.37 0.0 0.0 14.9
 shap  5 5
END
############################################################
# MATERIAL
############################################################
# Lexan
MATERIAL  1
use ko 121
koinput isol -1 cmu 0.0232 y 0.001
matinput  rho  1.196 czero 1.4 qfb .15 crq .1
          pmin -0.002 epsfail 0.8  v0 1.0
          eosvmin 0.5 eosvmax 1.5
advinput advmat 1 rlxwmat 4.0  rlxumat .0
end
# Ta
MATERIAL  2
use ko 77
koinput isol -1 cmu 0.690 y 0.0077
matinput  rho  16.69 czero 1.4 qfb .15 crq .1
          pmin -0.044 epsfail 0.8  v0 1.0
          eosvmin 0.5 eosvmax 1.5
          e0 0.0
advinput advmat 1 rlxwmat 12.0  rlxumat .0
end
# HE Comp-B
MATERIAL  3
koinput iform 15 isol -1 cmu  0.0354  y 0.002
   refdp 1.70 ap 5.57483 bp 0.078301 wp 0.34  rp1 4.5  rp2 1.2 cmp 1.e-5
   refdr 1.70 ar 1479.0  br -0.05261 wr 0.912 rr1 12.0 rr2 1.2 cmr 2.4868e-5
   ccrit 0.01 freq 44.0 frer 0.222 eetal 4.0 ilim 0.3
   grow1 531.0 es1  0.222 ar1 0.667 em 2.0 glim 1.0
   grow2 0.0   es2  0.333 ar2 1.0   en 3.0 clim 0.0
   eps 0.001 q 0.081 t0 298.0 fcut 1.e-10 brnli 0.03
```

```
   bhe 0.0
matinput  rho  1.70 czero 1.4 qfb .15 crq .1
          pmin -0.000001   v0 1.043
          eosvmin 0.5 eosvmax 50.0
#         e0 -5.036918e-3
advinput advmat 1 advtmat 55.0 rlxwmat 8.0  rlxumat .0
end
# Alum 6061 -
MATERIAL  4
use ko 25
koinput isol -1 cmu 0.276 y 0.0029
matinput  rho  2.70 czero 1.4 qfb .15 crq .1
          pmin -0.012 epsfail 0.5  v0 1.0
          eosvmin 0.5 eosvmax 1.5
          e0 5.07614e-7  # use with KO
advinput advmat 1 rlxwmat 3.0  rlxumat .0
end
# Steel
MATERIAL  5
use ko 28
koinput isol -1 cmu 0.77 y 0.0034
matinput  rho 7.90 czero 1.4 qfb .15 crq .1
          pmin -0.027 epsfail 0.5  v0 1.0
          eosvmin 0.5 eosvmax 1.5
advinput advmat 1 rlxwmat 6.0  rlxumat .0
end
# air
MATERIAL  6
koinput iform 5 isol 0 coef 0.4
matinput  rho 1.3e-3 e0 2.5e-6 v0 1 pmin 0.0
          eosvmin 1.e-5 eosvmax 1.e+2
advinput advmat 1 rlxwmat 1.0  rlxumat .0
end
```

```
# tp2
# test problem for reactive flow HE initiation
# 1.44km/sec detonation at 40 microseconds
############################
OUTPUT
nodeset vel_ints material  1
nodeset frees freesurface
restartvar default
#
plotac 1
stoptime 100.
dumpcycle 1 2 100 2000
dumptime 5.0 100.
plotcycle 1 2 100 2000
plottime  5.0 100.
table t1 0.0 1.0 1000.0 1.0
#
END
#####################################
# CONTROL parameter block
######################################################
CONTROL
# set timelimit for run in minutes
timelimit 1200
msgorder 1
ssvfcut .1
notify 1
dtinit 1.e-3
dtmax 1.0
dtmin 1.e-9
END
#########################################################
# HYDRO parameter block
#########################################################
HYDRO
# turn off pressure relaxation in mixed zones
presseq 0
qstop 1.e6
END
#########################################################
# ADVECTION parameter block
#########################################################
ADVECTION
advcycle 1
# relax zones into material prior to running analysis
advitercnt 50
ATCYCLE 3 advitercnt 1
advdtcon .2
ATCYCLE 3 advdtcon 0.1
rlxumin 0.0
rlxwprop 2
advpfmr 0.1
fracke 1
# sometimes best to relax mesh from initial configuration
# rlxginit 1
advdvmax 0.99
rlxmethod equipotential
# 3 materials in mixed zone = end of run, so prevent it
cvfcutx 1.0e-6
END
```

```
#############################################################
# BOUNDARY parameter block
#############################################################
BOUNDARY
# 1.38km/sec produces weak burn, 1.44km/sec detonation
VELOCITY vel_ints 0.0 0. 0.144
outflow  frees
pres_loadcurve frees  1.0e-6 table t1
END
#############################################################
# SHAPE parameter block
#############################################################
SHAPE
* Lexan projectile
 sphr  1  3.8  0.0 0.0 4.4
 shap  1 1
* Ta front plate
 cyl1  2 14.0  0.0 0.0 9.0  0.0 0.0 9.37
 shap  2 2
* Al outer ring
 cyl1  3 14.0  0.0 0.0 9.37 0.0 0.0 14.37
 shap  3 4
* HE cylinder
 cyl1  4 12.5  0.0 0.0 9.37 0.0 0.0 14.37
 shap  4 3
* Steel back plate
 cyl1  5 14.0  0.0 0.0 14.37 0.0 0.0 14.9
 shap  5 5
END
#############################################################
# MATERIAL
#############################################################
# Lexan
MATERIAL  1
use ko 121
koinput isol -1 cmu 0.0232 y 0.001
matinput  rho  1.196 czero 1.4 qfb .15 crq .1
          pmin -0.002 epsfail 0.8  v0 1.0
          eosvmin 0.5 eosvmax 1.5
advinput advmat 1 rlxwmat 4.0  rlxumat .0
end
# Ta
MATERIAL  2
use ko 77
koinput isol -1 cmu 0.690 y 0.0077
matinput  rho  16.69 czero 1.4 qfb .15 crq .1
          pmin -0.044 epsfail 0.8  v0 1.0
          eosvmin 0.5 eosvmax 1.5
          e0 0.0
advinput advmat 1 rlxwmat 12.0  rlxumat .0
end
# HE Comp-B
MATERIAL  3
koinput iform 15 isol -1 cmu  0.0354  y 0.002
   refdp 1.70 ap 5.57483 bp 0.078301 wp 0.34  rp1 4.5  rp2 1.2 cmp 1.e-5
   refdr 1.70 ar 1479.0  br -0.05261 wr 0.912 rr1 12.0 rr2 1.2 cmr 2.4868e-5
   ccrit 0.01 freq 44.0 frer 0.222 eetal 4.0 ilim 0.3
   grow1 531.0 es1 0.222 ar1 0.667 em 2.0 glim 1.0
   grow2 0.0   es2 0.333 ar2 1.0   en 3.0 clim 0.0
   eps 0.001 q 0.081 t0 298.0 fcut 1.e-10 brnli 0.03
```

```
   bhe 0.0
matinput  rho  1.70 czero 1.4 qfb .15 crq .1
          pmin -0.000001   v0 1.043
          eosvmin 0.5 eosvmax 50.0
#         e0 -5.036918e-3
advinput advmat 1 advtmat 55.0 rlxwmat 8.0  rlxumat .0
end
# Alum 6061 -
MATERIAL  4
use ko 25
koinput isol -1 cmu 0.276 y 0.0029
matinput  rho  2.70 czero 1.4 qfb .15 crq .1
          pmin -0.012 epsfail 0.5  v0 1.0
          eosvmin 0.5 eosvmax 1.5
          e0 5.07614e-7  # use with KO
advinput advmat 1 rlxwmat 3.0  rlxumat .0
end
# Steel
MATERIAL  5
use ko 28
koinput isol -1 cmu 0.77 y 0.0034
matinput  rho 7.90 czero 1.4 qfb .15 crq .1
          pmin -0.027 epsfail 0.5  v0 1.0
          eosvmin 0.5 eosvmax 1.5
advinput advmat 1 rlxwmat 6.0  rlxumat .0
end
# air
MATERIAL  6
koinput iform 5 isol 0 coef 0.4
matinput  rho 1.3e-3 e0 2.5e-6 v0 1 pmin 0.0
          eosvmin 1.e-5 eosvmax 1.e+2
advinput advmat 1 rlxwmat 1.0  rlxumat .0
end
```

```
# tp3
# test problem for reactive flow HE initiation
# 1.385km/sec HE burn that dies out
############################
OUTPUT
nodeset vel_ints material  1
nodeset frees freesurface
restartvar default
#
plotac 1
stoptime 100.
dumpcycle 1 2 100 2000
dumptime 5.0 100.
plotcycle 1 2 100 2000
plottime  5.0 100.
table t1 0.0 1.0 1000.0 1.0
#
END
#####################################
# CONTROL parameter block
######################################################
CONTROL
# set timelimit for run in minutes
timelimit 1200
msgorder 1
ssvfcut .1
notify 1
dtinit 1.e-3
dtmax 1.0
dtmin 1.e-9
END
#########################################################
# HYDRO parameter block
#########################################################
HYDRO
# turn off pressure relaxation in mixed zones
presseq 0
qstop 1.e6
END
#########################################################
# ADVECTION parameter block
#########################################################
ADVECTION
advcycle 1
# relax zones into material prior to running analysis
advitercnt 50
ATCYCLE 3 advitercnt 1
advdtcon .2
ATCYCLE 3 advdtcon 0.1
rlxumin 0.0
rlxwprop 2
advpfmr 0.1
fracke 1
# sometimes best to relax mesh from initial configuration
# rlxginit 1
advdvmax 0.99
rlxmethod equipotential
# 3 materials in mixed zone = end of run, so prevent it
cvfcutx 1.0e-6
END
```

```
###########################################################
# BOUNDARY parameter block
###########################################################
BOUNDARY
# 1.38km/sec produces weak burn, 1.44km/sec detonation
VELOCITY vel_ints 0.0 0. 0.1385
outflow  frees
pres_loadcurve frees  1.0e-6 table t1
END
###########################################################
# SHAPE parameter block
###########################################################
SHAPE
* Lexan projectile
 sphr  1  3.8  0.0 0.0 4.4
 shap  1 1
* Ta front plate
 cyl1  2 14.0  0.0 0.0 9.0  0.0 0.0 9.37
 shap  2 2
* Al outer ring
 cyl1  3 14.0  0.0 0.0 9.37 0.0 0.0 14.37
 shap  3 4
* HE cylinder
 cyl1  4 12.5  0.0 0.0 9.37 0.0 0.0 14.37
 shap  4 3
* Steel back plate
 cyl1  5 14.0  0.0 0.0 14.37 0.0 0.0 14.9
 shap  5 5
END
###########################################################
# MATERIAL
###########################################################
# Lexan
MATERIAL  1
use ko 121
koinput isol -1 cmu 0.0232 y 0.001
matinput  rho  1.196 czero 1.4 qfb .15 crq .1
          pmin -0.002 epsfail 0.8  v0 1.0
          eosvmin 0.5 eosvmax 1.5
advinput advmat 1 rlxwmat 4.0  rlxumat .0
end
# Ta
MATERIAL  2
use ko 77
koinput isol -1 cmu 0.690 y 0.0077
matinput  rho  16.69 czero 1.4 qfb .15 crq .1
          pmin -0.044 epsfail 0.8  v0 1.0
          eosvmin 0.5 eosvmax 1.5
          e0 0.0
advinput advmat 1 rlxwmat 12.0  rlxumat .0
end
# HE Comp-B
MATERIAL  3
koinput iform 15 isol -1 cmu  0.0354  y 0.002
   refdp 1.70 ap 5.57483 bp 0.078301 wp 0.34  rp1 4.5  rp2 1.2 cmp 1.e-5
   refdr 1.70 ar 1479.0  br -0.05261 wr 0.912 rr1 12.0 rr2 1.2 cmr 2.4868e-5
   ccrit 0.01 freq 44.0 frer 0.222 eetal 4.0 ilim 0.3
   grow1 531.0 es1 0.222 ar1 0.667 em 2.0 glim 1.0
   grow2 0.0   es2 0.333 ar2 1.0   en 3.0 clim 0.0
   eps 0.001 q 0.081 t0 298.0 fcut 1.e-10 brnli 0.03
```

```
# tp4
# test problem for reactive flow HE initiation
# 1.39km/sec detonation at ~ 60 microseconds
############################
OUTPUT
nodeset vel_ints material  1
nodeset frees freesurface
restartvar default
#
plotac 1
stoptime 100.
dumpcycle 1 2 100 2000
dumptime 5.0 100.
plotcycle 1 2 100 2000
plottime  5.0 100.
table t1 0.0 1.0 1000.0 1.0
#
END
#####################################
# CONTROL parameter block
######################################################
CONTROL
# set timelimit for run in minutes
timelimit 1200
msgorder 1
ssvfcut .1
notify 1
dtinit 1.e-3
dtmax 1.0
dtmin 1.e-9
END
#########################################################
# HYDRO parameter block
#########################################################
HYDRO
# turn off pressure relaxation in mixed zones
presseq 0
qstop 1.e6
END
#########################################################
# ADVECTION parameter block
#########################################################
ADVECTION
advcycle 1
# relax zones into material prior to running analysis
advitercnt 50
ATCYCLE 3 advitercnt 1
advdtcon .2
ATCYCLE 3 advdtcon 0.1
rlxumin 0.0
rlxwprop 2
advpfmr 0.1
fracke 1
# sometimes best to relax mesh from initial configuration
# rlxginit 1
advdvmax 0.99
rlxmethod equipotential
# 3 materials in mixed zone = end of run, so prevent it
cvfcutx 1.0e-6
END
```

```
############################################################
# BOUNDARY parameter block
############################################################
BOUNDARY
# 1.38km/sec produces weak burn, 1.44km/sec detonation
VELOCITY vel_ints 0.0 0. 0.139
outflow  frees
pres_loadcurve frees  1.0e-6 table t1
END
############################################################
# SHAPE parameter block
############################################################
SHAPE
* Lexan projectile
 sphr  1  3.8  0.0 0.0 4.4
 shap  1 1
* Ta front plate
 cyl1  2 14.0  0.0 0.0 9.0  0.0 0.0 9.37
 shap  2 2
* Al outer ring
 cyl1  3 14.0  0.0 0.0 9.37 0.0 0.0 14.37
 shap  3 4
* HE cylinder
 cyl1  4 12.5  0.0 0.0 9.37 0.0 0.0 14.37
 shap  4 3
* Steel back plate
 cyl1  5 14.0  0.0 0.0 14.37 0.0 0.0 14.9
 shap  5 5
END
############################################################
# MATERIAL
############################################################
# Lexan
MATERIAL  1
use ko 121
koinput isol -1 cmu 0.0232 y 0.001
matinput  rho  1.196 czero 1.4 qfb .15 crq .1
          pmin -0.002 epsfail 0.8  v0 1.0
          eosvmin 0.5 eosvmax 1.5
advinput advmat 1 rlxwmat 4.0  rlxumat .0
end
# Ta
MATERIAL  2
use ko 77
koinput isol -1 cmu 0.690 y 0.0077
matinput  rho  16.69 czero 1.4 qfb .15 crq .1
          pmin -0.044 epsfail 0.8  v0 1.0
          eosvmin 0.5 eosvmax 1.5
          e0 0.0
advinput advmat 1 rlxwmat 12.0  rlxumat .0
end
# HE Comp-B
MATERIAL  3
koinput iform 15 isol -1 cmu  0.0354  y 0.002
   refdp 1.70 ap 5.57483 bp 0.078301 wp 0.34  rp1 4.5  rp2 1.2 cmp 1.e-5
   refdr 1.70 ar 1479.0  br -0.05261 wr 0.912 rr1 12.0 rr2 1.2 cmr 2.4868e-5
   ccrit 0.01 freq 44.0 frer 0.222 eetal 4.0 ilim 0.3
   grow1 531.0 es1 0.222 ar1 0.667 em 2.0 glim 1.0
   grow2 0.0   es2 0.333 ar2 1.0   en 3.0 clim 0.0
   eps 0.001 q 0.081 t0 298.0 fcut 1.e-10 brnli 0.03
```

```
   bhe 0.0
matinput  rho  1.70 czero 1.4 qfb .15 crq .1
          pmin -0.000001   v0 1.043
          eosvmin 0.5 eosvmax 50.0
#         e0 -5.036918e-3
advinput advmat 1 advtmat 95.0 rlxwmat 8.0  rlxumat .0
end
# Alum 6061 -
MATERIAL  4
use ko 25
koinput isol -1 cmu 0.276 y 0.0029
matinput  rho  2.70 czero 1.4 qfb .15 crq .1
          pmin -0.012 epsfail 0.5  v0 1.0
          eosvmin 0.5 eosvmax 1.5
          e0 5.07614e-7  # use with KO
advinput advmat 1 rlxwmat 3.0  rlxumat .0
end
# Steel
MATERIAL  5
use ko 28
koinput isol -1 cmu 0.77 y 0.0034
matinput  rho 7.90 czero 1.4 qfb .15 crq .1
          pmin -0.027 epsfail 0.5  v0 1.0
          eosvmin 0.5 eosvmax 1.5
advinput advmat 1 rlxwmat 6.0  rlxumat .0
end
# air
MATERIAL  6
koinput iform 5 isol 0 coef 0.4
matinput  rho 1.3e-3 e0 2.5e-6 v0 1 pmin 0.0
          eosvmin 1.e-5 eosvmax 1.e+2
advinput advmat 1 rlxwmat 1.0  rlxumat .0
end
```

```
   bhe 0.0
matinput  rho  1.70 czero 1.4 qfb .15 crq .1
          pmin -0.000001   v0 1.043
          eosvmin 0.5 eosvmax 50.0
#         e0 -5.036918e-3
advinput advmat 1 advtmat 95.0 rlxwmat 8.0  rlxumat .0
end
# Alum 6061 -
MATERIAL  4
use ko 25
koinput isol -1 cmu 0.276 y 0.0029
matinput  rho  2.70 czero 1.4 qfb .15 crq .1
          pmin -0.012 epsfail 0.5  v0 1.0
          eosvmin 0.5 eosvmax 1.5
          e0 5.07614e-7  # use with KO
advinput advmat 1 rlxwmat 3.0  rlxumat .0
end
# Steel
MATERIAL  5
use ko 28
koinput isol -1 cmu 0.77 y 0.0034
matinput  rho 7.90 czero 1.4 qfb .15 crq .1
          pmin -0.027 epsfail 0.5  v0 1.0
          eosvmin 0.5 eosvmax 1.5
advinput advmat 1 rlxwmat 6.0  rlxumat .0
end
# air
MATERIAL  6
koinput iform 5 isol 0 coef 0.4
matinput  rho 1.3e-3 e0 2.5e-6 v0 1 pmin 0.0
          eosvmin 1.e-5 eosvmax 1.e+2
advinput advmat 1 rlxwmat 1.0  rlxumat .0
end
```